



AMUSENS

D6.3

Report on user needs for the development of a single sensor

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Abstract	This deliverable consolidates insights from user research and co-design sessions to define requirements for the AMUSENS single-sensor platform. The results establish core expectations—including accuracy, usability, privacy, and actionable feedback—that will guide subsequent technical development and validation activities.
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Keywords

Human-centred design; Co-design; Sensor technology; Personal exposure; Breath analysis; Data privacy; User requirements

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Executive Summary

Deliverable D6.3, *Report on User Needs for the Development of a Single Sensor*, presents the outcomes of Task 6.5 within Work Package 6 of the AMUSENS project. Its primary objective is to identify and translate user needs, expectations, and challenges into actionable requirements for the development of a single multi-material sensor and its associated digital ecosystem. This user-centred evidence base supports a responsible and socially aligned technological development process, ensuring that the AMUSENS platform is technically robust, ethically grounded, and fit for real-world adoption across environmental and health-related applications.

To achieve this objective, a mixed-method methodology was employed, combining quantitative surveys and qualitative co-design workshops conducted across different European countries. Participants included citizens, clinicians, researchers, and technology developers, ensuring a diverse representation of target user groups. Two primary use cases framed the research: Personal Exposure (environmental air-quality monitoring) and Breath Analysis (health, metabolic and respiratory monitoring). Insights were analysed and synthesised into shared and scenario-specific requirements, following a structured human-centred design and Responsible Research and Innovation (RRI) approach.

Across both use cases, users expressed a clear and consistent set of core priorities: **accuracy and reliability**, **ease of use**, and **strong data-privacy safeguards** represent essential conditions for adoption. Participants expect **interpreted, actionable feedback**, supported by intuitive, low-friction interfaces. The **mobile application** is identified as the main touchpoint for accessing information, managing data, and interacting with system functions. Additional critical aspects include **comfort and portability**, **battery autonomy**, and **affordability**, particularly for personal-use contexts. Breath-analysis users emphasised clinical trust, hygiene, and professional validation, whereas personal-exposure users prioritised wearability and continuous, unobtrusive monitoring.

The deliverable consolidates these insights into a prioritised hierarchy of user requirements, a set of design principles, and recommendations for the technical Work Packages (WPs). These include guidance on hardware design (e.g., portability, autonomy, hygiene), software architecture (e.g., transparency, progressive disclosure), and data governance (e.g., privacy-by-design, local-first processing, interoperability). The outcomes form a structured foundation for steering development activities in the project.

Overall, this deliverable provides a comprehensive, empirically grounded framework for ensuring that the AMUSENS single-sensor solution is **scientifically validated**, **user-centred**, and **trust-worthy**, enabling technological innovation that is socially responsive and aligned with ethical standards. The results contribute to AMUSENS' impact and exploitation objectives by strengthening pathways for user acceptance, regulatory readiness, and downstream market adoption.

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Chapter 1 Introduction

The AMUSENS project aims to develop an advanced and adaptable gas-sensing platform by integrating multiple metal-oxide materials onto a single chip. This innovative approach enables scalable and selective detection of a wide range of gases, offering potential applications in health, safety, and environmental monitoring.

Within this framework, **Work Package 6 (WP6)** plays a central role in the functional characterization and performance testing of the single sensor developed under WP5. Activities in WP6 include controlled gas exposure experiments to build a comprehensive database of sensing responses, which will serve as the foundation for the development of artificial intelligence algorithms capable of selecting optimal material combinations for specific applications. At the conclusion of the project, this database will be made publicly available to support further research and innovation.

A fundamental principle of AMUSENS is ensuring that technological development is guided by **real-world user needs**. Deliverable **D6.3 – “Report on user needs for the development of a single sensor”** presents the results of **Task 6.5**, which establishes a human-centred design framework for the AMUSENS project. Specifically, this deliverable identifies and analyses user needs related to the single-sensor component of the platform, translating these into actionable requirements through co-design and participatory engagement activities.

This work builds on the foundations laid in **WP4**, which defined the target gases and initial use contexts. In particular, insights obtained through the **Task 4.4 survey** provided an initial understanding of relevant user profiles and potential applications for both the Personal Exposure and Breath Analysis use cases. These findings are briefly revisited in this deliverable to contextualize their contribution to the co-design activities conducted in Task 6.5.

The core of this deliverable is the analysis of three co-design workshops carried out as part of Task 6.5. One workshop was conducted face-to-face in Spain, another online with Spanish participants, and a third online with participants from various European countries. All sessions shared the objective of gathering input from citizens and potential end-users, focusing on their expectations, preferences, and concerns regarding gas-sensing technologies. Insights derived from these engagements have directly informed the ongoing development of the AMUSENS platform by translating user perspectives into technical and functional requirements. Furthermore, Task 6.5 contributes to defining requirements for stress-estimation use cases, broadening the applicability of the platform.

Findings from Task 6.5 will inform subsequent activities in WP8, supporting the testing phase of the complete multipixel sensor. Specifically, the user requirements and design principles identified in this task will serve as a reference framework for the validation protocols, ensuring that performance tests reflect real user expectations and practical conditions of use. In this way, WP8 not only verifies the sensor’s technical functionality but also evaluates its suitability, usability, and reliability from an end-user perspective.

More broadly, WP6 functions as a critical link between earlier and later stages of development: it builds upon WP4 (preparation phase) and WP5 (single-sensor processing), and its results provide inputs for WP7 (multi-pixel sensor processing), WP8 (multi-pixel sensor testing), and WP10 (testing of the platform on use-case applications).

The primary objective of this deliverable is to document the needs, expectations, and challenges identified by potential end-users in relation to the single sensor. These findings—derived from co-design and user engagement activities—are synthesized into concrete requirements that will guide the ongoing design and validation process. In doing so, this deliverable ensures that the AMUSENS platform advances in line with **Responsible Research and Innovation (RRI)** principles and the integration of **Social Sciences and Humanities (SSH)**, ensuring that technological development remains grounded in user trust, societal relevance, and ethical responsibility.

The remainder of this document is structured as follows:

- **Context and Background:** Introduces the conceptual and scientific background underpinning AMUSENS, including the relevance of air pollution monitoring, advances in breath analysis, and the rationale for adopting a user-centred approach.
- **Methodology:** Describes the user-centred co-design framework applied in AMUSENS, detailing the adapted Double Diamond process, ethical and data protection procedures, and the specific methodologies used for the *Personal Exposure Use Case*, *Breath Analysis Use Case*, and the *European Validation Workshop*.
- **Results:** Presents the outcomes of the surveys and co-design workshops conducted across the three use cases, highlighting key insights, user priorities, and consolidated findings derived from participatory activities.
- **Consolidated User Requirements:** Synthesizes the identified needs into actionable design principles and recommendations for the technical work packages, providing a clear link between user expectations and sensor development.
- **Summary and Conclusion:** Summarizes the main findings and discusses the implications for the next phases of AMUSENS, including validation and further development of the multi-pixel sensor platform.
- **Annexes:** Full survey instruments in English, stakeholder mapping tables, and complementary materials.



Chapter 2 Context and Background

2.1 The importance of Air Pollution Monitoring

Monitoring air pollution is essential to raising public awareness and fostering behavioural change. Reliable tracking provides the data necessary to understand pollution sources, concentrations, and impacts, empowering both individuals and communities to take informed actions that improve air quality.

A robust monitoring framework allows for the identification of specific environments or activities that increase exposure and supports the design of interventions to mitigate risk. Individual motivations for monitoring air quality vary widely, from managing existing health conditions to satisfying curiosity about environmental surroundings. Ultimately, awareness of personal exposure levels enables citizens to adopt proactive strategies to reduce health risks and enhance overall well-being.

2.2 The Role of Breath Analysis in Complementary Monitoring

Concerns about air pollution naturally extend to its internal biological effects. In this regard, **breath analysis** emerges as a complementary and powerful diagnostic approach. As a **non-invasive method**, it offers valuable insight into an individual's physiological state through the detection of **volatile organic compounds (VOCs)** in exhaled breath, which serve as biochemical fingerprints of metabolic processes.

A well-structured analytical framework for breath monitoring is essential to identify disease-specific biomarkers, trace the translation of environmental exposures into internal biological responses, and develop new preventive and diagnostic strategies. As with air quality monitoring, personal motivations for assessing breath composition vary from tracking infections and metabolic health to monitoring general well-being. In both cases, enhanced understanding supports informed decision-making and timely medical intervention.

2.3 Main Sources of Indoor Air Pollution

Indoor air pollution refers to the contamination of air within buildings, which can lead to a wide range of health impacts (Kodali, Pathuri, & Rajnarayanan, 2020). The composition of indoor air is influenced by multiple factors, with key pollutants including Volatile Organic Compounds (VOCs) and Particulate Matter (PM).

A broad variety of household items—such as paints, cleaning products, furniture, printers, and adhesives—release VOCs linked to adverse health effects (Maung et al., 2022). Consumer products and occupant activities together contribute to approximately 40% of total VOC emissions (Halios et al., 2022).

Cooking is another major source, generating both particulate and gaseous pollutants. Studies estimate that cooking activities account for around 22% of daily PM_{2.5} exposure (Sun & Wallace, 2021). Likewise, combustion from heating or smoking emits carbon monoxide, nitrogen dioxide, PM, and polycyclic aromatic hydrocarbons, depending on the fuel type used (Angell, Grimsrud, & Lee, 2005).

Routine activities such as cleaning can also degrade indoor air quality by releasing VOCs and re-suspending settled particles (Angell et al., 2005; Abt et al., 2000). Additionally, building materials and furniture are persistent sources of VOCs and formaldehyde, particularly in new constructions (Maung et al., 2022). Even human presence contributes by elevating CO₂ levels and disturbing particulate matter (Abt et al., 2000).

Finally, pollutants from outdoor sources can infiltrate indoor environments through ventilation systems, garages, and building envelopes. Poor ventilation can lead to the accumulation of these contaminants, significantly reducing indoor air quality.

2.4 Health Impacts of Prolonged Exposure to Indoor Pollutants

Exposure to indoor air pollutants such as biomass smoke, PM, nitrogen dioxide, VOCs, formaldehyde, and tobacco smoke, has been associated with numerous health effects (Angell et al., 2005; Bruce, Pérez-Padilla, & Albalak, 2002; Hulin et al., 2012).

Documented respiratory effects include reduced blood oxygen saturation, increased airway inflammation (as measured by fractional exhaled nitric oxide, FeNO), diminished lung function, and exacerbation of asthma (Maung et al., 2022; Vardoulakis et al., 2020). Even short-term exposure to VOCs and nitrogen dioxide has been linked to upper airway symptoms and asthma, particularly in children (Maung et al., 2022).

Beyond respiratory outcomes, indoor air pollution contributes to systemic health issues, including cardiovascular effects, lower birth weights, elevated infant mortality, and increased risk of certain cancers such as leukaemia and nasopharyngeal carcinoma (Angell et al., 2005; Bruce et al., 2002; Maung et al., 2022).

Vulnerable populations such as children, pregnant women, and individuals with pre-existing respiratory conditions are particularly at risk. Women in developing countries often experience disproportionately high exposure levels due to cooking and heating practices (Bruce et al., 2002).

2.5 Literature Review: Advances in Breath Analysis

Breath analysis has rapidly evolved as a non-invasive method for health monitoring, leveraging the complex mixture of VOCs and trace gases in exhaled breath to reflect metabolic and biochemical processes (Das & Pal, 2020; Kim et al., 2024).

Human breath contains thousands of VOCs, typically in the ppm to ppt range, originating from both endogenous metabolism and exogenous environmental exposure (Di Natale et al., 2014). Accurate analysis requires advanced techniques, ranging from Gas Chromatography-Mass Spectrometry (GC-MS) and Proton Transfer Reaction-Mass Spectrometry (PTR-MS) to Selected Ion Flow Tube-Mass Spectrometry (SIFT-MS), offering high sensitivity and specificity (Das & Pal, 2020; Di Natale et al., 2014). Real-time methods such as Secondary Electrospray Ionization Mass Spectrometry (SESI-MS) can detect larger biomolecules with comparable precision (Martinez-Lozano Sinues et al., 2014; Roquencourt et al., 2023).

Emerging solid-state sensor technologies—including **metal oxide sensors**, carbon nanotubes, graphene-based systems, and electronic noses (e-noses)—are being combined with machine learning algorithms to enable portable, point-of-care applications. Nonetheless, challenges such as humidity interference, cross-sensitivity, and signal stability persist (Woehrle et al., 2024). Standardized collection methods, particularly those targeting end-tidal (alveolar) air, are critical for ensuring measurement reliability and minimizing contamination (Del Orbe et al., 2022).

Specific breath biomarkers have demonstrated strong diagnostic potential. For example:

- **Acetone** indicates metabolic conditions such as diabetes or ketosis (Das & Pal, 2020).
- **Ammonia** levels can reveal liver or kidney dysfunction (Di Natale et al., 2014).
- **Nitric oxide (NO)** serves as a marker for airway inflammation in asthma.
- **Hydrogen sulfide** and related volatile sulphur compounds correlate with halitosis and may reflect systemic diseases such as COPD or chronic renal failure (Fenn et al., 2023).

Beyond single compounds, breathprint patterns have been shown to differentiate between diseases such as COPD (Martinez-Lozano Sinues et al., 2014), COVID-19 (Roquencourt et al., 2023; Woehrle et al., 2024), and Parkinson's disease (Stott et al., 2022). Breath analysis also offers potential in lifestyle and wellness applications, such as monitoring fat metabolism during exercise (Del Orbe et al., 2022) or detecting stress-related biochemical responses (Santos et al., 2020).

2.6 User-Centred Requirements for Real-Life Applications

The AMUSENS project adopts a **user-centred design (UCD)** philosophy, ensuring that technological development is guided by real-world needs rather than purely technical considerations. Rooted in the framework formalized by Norman and Draper (1986) and further discussed by Chammas, Quaresma, & Mont’Alvão (2015), UCD emphasises iterative engagement with users throughout the entire design process, from identifying needs to testing and validation.

Within AMUSENS, end-users are engaged as **active co-creators** through structured **co-design workshops**. This participatory approach integrates user feedback on usability, ergonomics, device format (e.g., wearable versus stationary), and trust in data management. The insights gathered are systematically incorporated into sensor development to ensure contextual relevance and high usability.

This inclusive, iterative methodology strengthens both the **technical robustness** and **societal relevance** of the sensor platform. By integrating co-creation and prototype testing, AMUSENS ensures that its solutions adapt to diverse application contexts and respond effectively to the needs, expectations, and constraints of different user profiles.

2.7 From User Needs to Technical Specifications

To operationalize the high-level user-centred objectives of AMUSENS, a structured methodology was designed to capture and analyse user insights for both the Personal Exposure and Breath Analysis use cases. This process combines **co-design workshops** and **complementary surveys**, applying a **mixed-methods approach** that integrates qualitative and quantitative data.

The following chapter presents this methodological framework in detail, outlining how user needs and expectations are systematically translated into actionable requirements that guide sensor design and validation. In addition, this process contributes directly to the project’s impact and exploitation objectives by ensuring that technological development aligns with user demand, societal value, and market potential.

Chapter 3 Methodology

3.1 Overall Approach: User-Centred Co-Design driven by Design Thinking

The methodology applied in **Task 6.5** of AMUSENS to identify end-user needs is grounded in a **User-Centred Design (UCD)** philosophy, informed by the principles of **Design Thinking**. This combined approach ensures that the sensor development process remains guided by user perspectives, real-world contexts, and iterative co-creation rather than by purely technical considerations.

3.1.1 Design Thinking as a Guiding Framework

Design Thinking represents a contemporary, human-centred problem-solving approach that prioritises users' needs and experience (Brown, 2008). It operates on three core pillars—**empathy**, **ideation**, and **iteration**—which together form a dynamic process of discovery and refinement.

- **Empathy** involves immersing in the user's context to gain a deep understanding of their needs, emotions, and motivations, thereby challenging assumptions.
- **Ideation** encourages the generation of diverse and creative solution pathways, fostering open exploration without early judgment.
- **Iteration** refers to the continuous cycle of prototyping, testing, and refining ideas based on user feedback, allowing progressive alignment between user expectations and technical solutions (Brown, 2008; Razzouk & Shute, 2012).

Unlike traditional analytical approaches, Design Thinking adopts a **solution-oriented stance** from the outset, integrating human desirability, technological feasibility, and economic viability into each design phase (Harvard Business School Online, n.d.; IDEO U, n.d.). Its iterative and non-linear nature makes it particularly suitable for complex technological development, such as sensor design within AMUSENS (Growth Tribe, n.d.; Interaction Design Foundation, n.d.).

3.1.2 User-Centred Design Principles

User-Centred Design (UCD) operationalises this human-centred philosophy through concrete processes and techniques that embed users directly into the design and development cycle. Originating from *User-Centered System Design* (Norman & Draper, 1986), UCD is both a philosophy and a methodological framework in which end-users actively influence the evolution of a product or service (Lanter & Essinger, 2017).

The key principles of UCD include (Chammas et al., 2015):

- **Explicit understanding** of users, their tasks, and their environments.
- **Active user involvement** throughout the design and development process.
- **Iterative design**, guided by user-focused evaluation at every stage.
- **Attention to the complete user experience**, encompassing perceptions before, during, and after use.
- **Multidisciplinary collaboration**, ensuring that diverse expertise informs design decisions.

According to Eason (1988), user engagement can occur at multiple levels:

- **Primary users** – individuals who directly interact with the system or device.
- **Secondary users** – those who engage occasionally or via intermediaries.
- **Tertiary users** – individuals indirectly affected by the system or involved in purchasing or decision-making.

The success of UCD is ultimately evaluated by **usability outcomes**—how effectively users can achieve their objectives—and by **user satisfaction** with the overall experience (Lanter & Essinger, 2017).

3.1.3 Relevance to Sensor Development

The integration of UCD and Design Thinking has proven effective in sensor technology development. These approaches have been used in creating **smart gas sensors for IoT applications** (SAP Community, n.d.), **wearable health monitors** (Baumann & Stone, 2023), and **smart apparel** (Imbesi & Scataglini, 2021). UCD has also demonstrated value in designing **environmental monitoring devices** with interfaces accessible to non-experts (Ceccarini, Mirri, & Prandi, 2022).

Such methodologies have even been applied in projects using **low-cost** sensors for emotional state detection, demonstrating their relevance to AMUSENS (Francese et al., 2020).

Nevertheless, applying UCD presents several challenges (Chammas et al., 2015), including limited team familiarity, resource constraints, and project scope shifts. Overcoming these requires leadership commitment, structured planning aligned with ISO 9241-210 (Chammas et al., 2015) and evidence-based decision-making derived from user data rather than assumptions.

In AMUSENS, co-design and co-creation are the central expressions of this approach. Users are engaged not merely as informants but as **partners in the design process**, participating in iterative development cycles and contributing directly to the refinement of prototypes and use-case applications.

3.2 Framework: Adapted Double Diamond Process

To structure and guide the UCD and co-design activities, the **Double Diamond methodology** (Design Council, n.d.) was adopted as the **operational framework**. This model (Figure 1) visualises the innovation journey through four sequential phases—**Discover, Define, Develop, and Deliver**—structured around alternating cycles of **divergent** and **convergent** thinking (Design Council, n.d.; Majka, 2024).

This cyclical process ensures both the accurate identification of the right problem (first diamond) and the creation of the most effective solution (second diamond) (Norman, 2013).

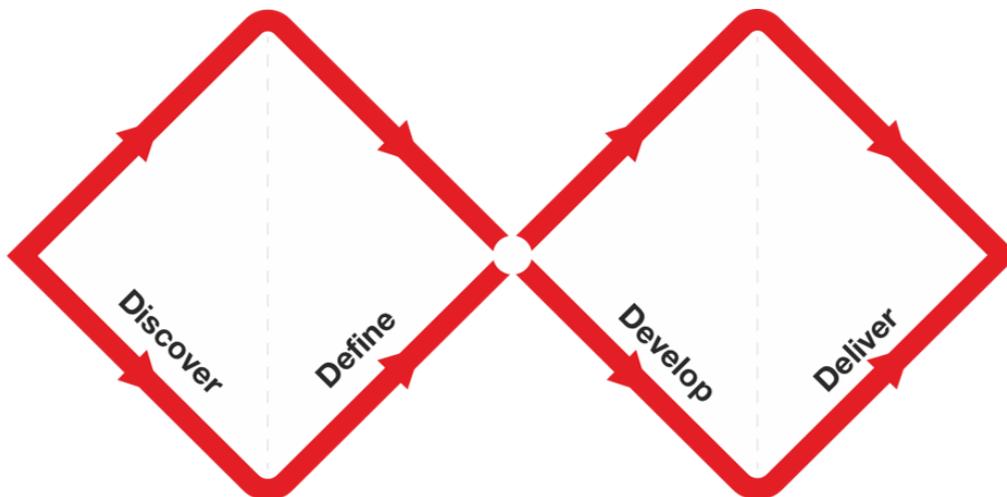


Figure 1. The Double Diamond model illustrating the four iterative phases of divergent and convergent thinking. Source: (Design Council, n.d.).

3.2.1 The Four Phases of the Double Diamond

1. Discover (Divergent Thinking)

Goal: Understand, don't assume.

This phase emphasises empathy and exploration. It involves desk research, surveys, and initial engagement activities to gain a broad understanding of user needs, behaviours, and contexts (Gustafsson, 2019; Majka, 2024).

2. Define (Convergent Thinking)

Goal: Synthesize and focus.

Insights from the discovery phase are analysed and synthesized to articulate clear problem statements and define actionable user requirements (Design Council, n.d.).

3. Develop (Divergent Thinking)

Goal: Explore potential solutions.

Building on the defined problem space, this phase generates and prototypes multiple potential solutions. Co-design workshops play a central role here, enabling stakeholders to co-create and evaluate features, formats, and functionalities (Gustafsson, 2019; Majka, 2024).

4. Deliver (Convergent Thinking)

Goal: Refine and validate.

In this final phase, the concepts are validated and refined through testing and feedback, leading to a consolidated set of user requirements ready for technical implementation (Gustafsson, 2019; Majka, 2024).

3.2.2 Application in AMUSENS

The **Double Diamond** model was **adapted** to the specific flow of user-needs identification and sensor development in AMUSENS (Figure 2). Its flexibility supports iterative validation while aligning with the project’s multidisciplinary and translational nature—bridging scientific research, technology development, and market-oriented design (Design Council, n.d.).

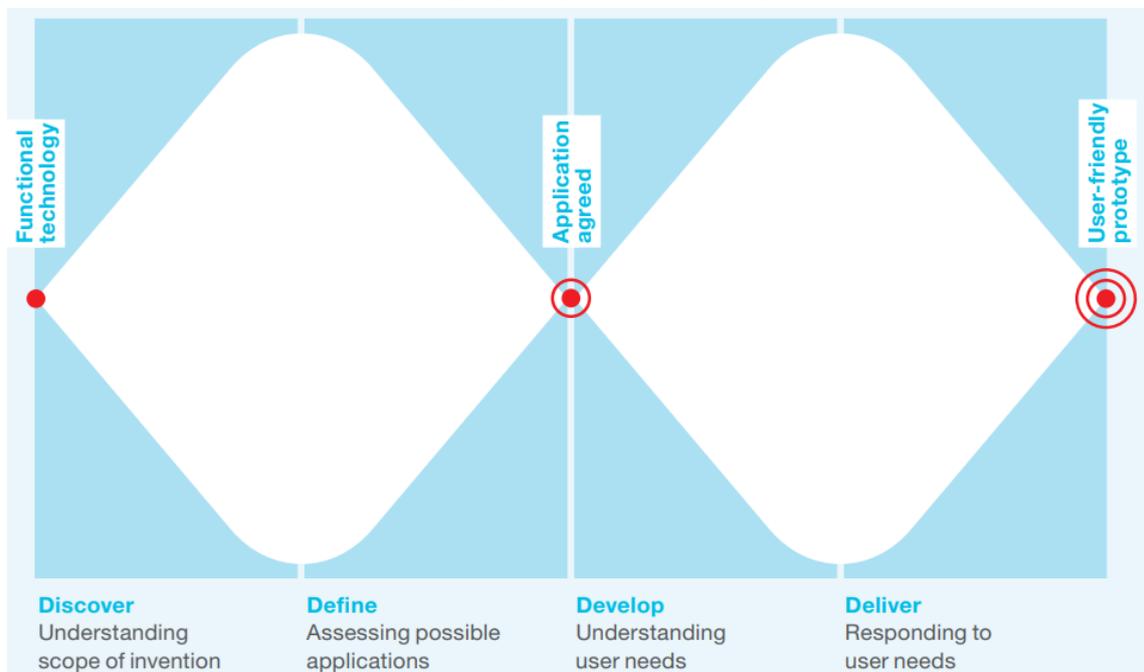


Figure 2. The Double Diamond process adapted to the commercialization of science and technology, illustrating its relevance to AMUSENS user-needs identification. Source: Design Council (n.d.).

- **Phase 1 – Discover:** Initiated through desk research and two parallel quantitative surveys (one per use case: *Personal Exposure* and *Breath Analysis*), collecting baseline data on motivations, perceptions, and preferences. Initial local co-design workshops expanded this phase, using exploratory tools such as *User Journey Mapping* to uncover latent needs.
- **Phase 2 – Define:** Combined quantitative survey findings and qualitative workshop results were analysed to cluster themes and synthesise core user requirements.
- **Phase 3 – Develop:** Conducted through co-design workshops that explored potential solutions, including prototypes and interface features such as *visual indicators* and *data reliability cues*.
- **Phase 4 – Deliver:** Implemented through a European-level online workshop designed to validate and refine user-derived requirements with a broader audience. This phase consolidated results into final, generalisable user specifications to inform subsequent technical work packages.



This structured, iterative process ensured that user feedback remained an integral part of each development stage, promoting both scientific robustness and user relevance.

3.3 Ethical Framework and Data Protection

All activities involving human participants within WP6 were conducted under a rigorous ethical framework, ensuring compliance with the **General Data Protection Regulation (GDPR)**, **Organic Law 3/2018** (Spain), and the **LIST Code of Ethics**. This framework was applied consistently across the **three co-design workshops** held within the AMUSENS project—covering both use cases (Personal Exposure and Breath Analysis) and the joint European session—guaranteeing ethical integrity, participant protection, and full alignment with Horizon Europe requirements.

3.3.1 Ethical Validation Process

A detailed protocol governing the engagement with human participants was developed by Science For Change (SFC) and submitted for review to the **Ethics Committee of the Luxembourg Institute of Science and Technology (LIST)**, the project coordinator. The decision to seek LIST's review followed consultations with the **AMUSENS Ethics Advisor** and multiple local ethics committees in Spain, which confirmed that they could not assess external research activities.

The LIST Ethics Committee conducted a formal evaluation and issued a **favourable** opinion on 28 May 2025, identifying no critical ethical concerns. The committee provided two specific recommendations to ensure full compliance, both of which were implemented in the execution of all workshops:

- **Data Protection:** In case of data access by LIST researchers, consultation with the **LIST Data Protection Officer (DPO)** must be carried out to verify full compliance with GDPR and internal policies.
- **Workshop Conduct and Informed Consent:** The organisation of the workshops by SFC must follow best practices for the ethical treatment of participants, including the prior collection of informed consent and transparent communication about data use.

These recommendations were fully adhered to throughout the implementation of all co-design sessions.

3.3.2 Participant Engagement and Informed Consent

The workshops aimed to explore user perceptions, expectations, and design preferences related to the AMUSENS sensor platform.

No participants were exposed to real or simulated substances, nor were they asked to provide personal or health-related information. The activities focused exclusively on perceptions of air quality, breath analysis, and sensor interaction.

Participation was entirely voluntary and based on **explicit informed consent**. Before each session, participants received:

- A **Participant Information Sheet**, explaining the study's purpose, data collection scope, and management procedures.
- An **Informed Consent Form**, detailing confidentiality safeguards, data protection rights (access, rectification, and erasure), and the right to withdraw at any time without consequences.

Two consent versions were made available: a short summary and a longer, detailed version for participants seeking additional information. This ensured fully informed and voluntary participation in accordance with Articles 34–38 of the LIST Code of Ethics.

3.3.3 Data Protection and GDPR Compliance

Comprehensive measures were implemented to ensure full compliance with GDPR and national data protection regulations:

- **Data Controller:** Science For Change, S.L. (Barcelona, Spain). Contact details of the Data Protection Officer were provided to all participants.
- **Pseudonymisation and Confidentiality:** All personal data (e.g., registration forms, notes, and transcripts) were pseudonymised. Identifying information was stored separately under restricted access, accessible only to one authorised researcher.
- **Data Sharing and Retention:** Pseudonymised data were shared securely among AMUSENS partners for research purposes only. Data transfers were encrypted, and only aggregated, anonymised data may be published in project reports or scientific outputs.
- **Image Use:** Separate, explicit consent was obtained for the use of photographs or screenshots for dissemination purposes. Participants could freely refuse without affecting their participation.
- **Participant Rights:** All participants were informed of their rights under GDPR, including access, correction, deletion, portability, and objection. Contact details for both SFC's DPO and the Spanish Data Protection Agency were provided.

3.3.4 Recruitment, Selection Criteria, and Quality Assurance

Recruitment aimed to ensure diversity in gender, age, ethnicity, and professional background, consistent with Article 41 of the LIST Code of Ethics. Participants were invited through the SFC Community, social media, and consortium partner networks. To ensure the quality and validity of the sample, the following procedures were established:

3.3.4.1 Inclusion and Exclusion Criteria

To ensure a rigorous selection process aligned with the study's objectives, the following specific criteria were applied to all participants:

- **Inclusion Criteria:**
 - **Age:** Adults (18 years or older).
 - **Language:** Proficient in the language of the workshop (Spanish for local sessions; English for the European session) to ensure active participation.
 - **Consent:** Willingness and capacity to sign the informed consent form and agree to data processing terms.
 - **Profile:** Interest in air quality, wellness monitoring, technology development, or relevant professional expertise.
- **Exclusion Criteria:**
 - Inability to provide informed legal consent.
 - Conflict of interest that could compromise the integrity of the co-design process.
 - Failure to complete the quality control verification during registration (see below).

3.3.4.2 Verification of Participants

To mitigate the risk of fraudulent registrations (e.g., bots or individuals solely motivated by incentives without genuine intent to participate), specific quality control measures were integrated into the registration forms:

1. **Control Questions:** The forms included specific logic checks and open-ended motivation questions (e.g., "Why are you interested in this specific workshop?"). These questions require contextual reasoning that prevents automated bots from completing the form.
2. **Manual Validation:** All registrations underwent a manual review process to filter out incoherent responses or suspicious patterns. Only validated profiles received the final invitation and meeting link.

3.3.4.3 Selection Procedure and Overbooking

For the workshops conducted in this task, the number of valid applications remained within the manageable capacity of the sessions. Therefore, **no eligible applicant had to be excluded**, and all validated registrants were invited to participate.



However, a contingency plan was established in case of oversubscription. Had the number of applicants exceeded the workshop capacity, a selection process based on **sociodemographic quotas** would have been triggered. This protocol prioritised diversity in gender, age, and professional background to ensure maximum representativeness of the target user groups.

3.3.5 Alignment with LIST Ethical Standards

All activities adhered to the principles established in Sections 5.3 and 5.5 of the LIST Code of Ethics, ensuring:

- Transparent communication of the study's purpose, funders, and use of results (Art. 34).
- Explicit, informed consent prior to participation (Art. 35).
- Respect for participants' rights, dignity, and autonomy (Art. 36).
- Protection from physical or psychological harm (Art. 37).
- Data protection and secure management consistent with GDPR (Art. 60–63).

3.3.6 Summary

This ethical and data protection framework ensured that all AMUSENS co-design workshops were conducted with the highest standards of **transparency, inclusiveness, and participant protection**. The protocol, validated by the LIST Ethics Committee, established a replicable model for responsible user engagement that combines scientific integrity with ethical and legal compliance, fully in line with **Responsible Research and Innovation (RRI)** principles.

3.4 Stakeholder Mapping and Expert Identification

While the co-design workshops described in the following sections focused primarily on end-users to capture daily-life requirements and usability needs, AMUSENS acknowledges that the success of sensor technology relies on a broader ecosystem. To address this, a comprehensive initial Stakeholder Mapping was conducted to identify key actors across the value chain who are critical for technical validation, regulatory compliance, and market uptake.

This mapping was performed prior to the specific use-case activities to guide the surveys and to prepare the ground for future validation phases. The identification strategy followed a **Quadruple Helix approach**, classifying stakeholders into four distinct categories to ensure a balanced representation beyond the academic sphere:

- **Academic & Research:** Universities and research institutes providing scientific validation and technological benchmarking.
- **Industry & Technology Developers:** Sensor manufacturers, SMEs, and software developers essential for ensuring the device's producibility and scalability.
- **Public Authority & Regulatory:** Agencies responsible for air quality standards and medical device certification to ensure future compliance.
- **Civil Society:** Medical societies and NGOs that represent the final beneficiaries and advocate for technology adoption.

The mapping covered the consortium's core countries (Spain, France, Germany, Italy, Greece) and key innovation hubs (Switzerland and UK among others). The resulting database, which lists the identified organisations without personal data to comply with GDPR, is provided in Annex 1. Stakeholder Mapping – Personal Exposure and

Annex 2. Stakeholder Mapping – Breath Analysis. This stakeholder map not only supported the distribution of surveys but also serves as the recruitment pool for the upcoming technical validation workshops, ensuring that the limitations of a purely academic co-design are addressed in the subsequent phases of the project.

3.5 Personal Exposure Use Case

3.5.1 Survey Methodology

3.5.1.1 Objectives and Rationale

The first survey focused on the **Personal Exposure Use Case** within AMUSENS. Its primary objective was to identify **user perspectives, needs, and preferences** related to **personal gas exposure monitoring**, with the ultimate goal of informing the design of a user-driven sensor platform.

The survey aimed to determine **who could benefit most** from this type of monitoring technology and **how it should be designed and implemented** to meet real user requirements. Specifically, the research explored:

- Desired sensor features and usability aspects.
- Practical use-case scenarios.
- Data interaction and communication preferences.
- Trust, data reliability, and sharing considerations.

Findings from this survey directly informed the design of the co-design workshops, identifying priority topics for further participatory exploration.

3.5.1.2 Questionnaire Design

The survey instrument consisted of an **online questionnaire** (see Annex 3. Preliminary questionnaire on personal exposure use case for the full instrument in English). The items were developed based on insights from **WP4** and cited sources.

The survey was open for two weeks (12–27 February 2025) and was hosted on Google Forms (Google Workspace). To ensure accessibility and inclusion, the questionnaire was translated into English, Spanish, French, Italian, and German. Partner organisations reviewed each version to ensure linguistic accuracy and contextual relevance:

- German: *Sciosense*
- Italian: *UNIBS*
- French: *IMT, LIST*
- Spanish: *Science For Change (SFC)*

Before beginning the survey, participants received:

- A short description of the AMUSENS project, including an explanatory video link.
- A brief explanation of the survey's purpose and objectives.
- A data protection disclaimer in compliance with *European Regulation 2016/679 (GDPR)*.

Proceeding with the questionnaire was conditional upon explicit acceptance of the data protection terms.

3.5.1.3 Structure and Content

The questionnaire was structured into five sections (refer to Annex 4. Dimensions and items of the Personal Exposure Use Case survey for detailed Dimensions and items of the Personal Exposure Use Case survey) designed to progressively move from general context to detailed user preferences.

- **Section 0 – General Information:**
Collected sociodemographic data (education level, occupation, predominant work environment).
- **Section 1 – General Understanding and Motivation:**
Explored participants' reasons for interest in exposure monitoring (e.g., health concerns, research purposes, curiosity) and their self-assessed level of knowledge on indoor air quality monitoring (“None” to “Specialist”). It also examined perceived priority locations for exposure monitoring (e.g., workplaces, homes, schools).
- **Section 2 – Sensor Application:**
Investigated user preferences for sensor typology (wearable, fixed, or integrated into a mobile instrument) and desired technical features (e.g., real-time data display, wireless connectivity). Open-ended items collected ergonomic or environmental considerations and acceptable use duration.
- **Section 3 – Utility and Interpretation of Data:**
Explored data utility, prioritised parameters (e.g., gas concentration, cumulative dose), and user preferences for real-time versus averaged data. Respondents were also asked about their willingness to periodically recharge the device for improved accuracy.
- **Section 4 – Awareness and Behavioural Change Potential:**
Addressed communication and behavioural aspects, including:
 - Data visualisation preferences (e.g., colour codes, descriptive labels, icons).
 - Trust and reliability factors.
 - Willingness to share complementary information.
 - Preferences for information delivery channels (on-sensor display, app, expert interpretation).
 - Interest in contextual features such as outdoor air quality display.

Responses combined closed-ended (categorical, ordinal, binary) and open-ended formats to enable both statistical and interpretative analysis.

3.5.1.4 Sampling and Recruitment

A total of **108 respondents** from various European countries completed the survey. The majority were **university-educated (99%)** and reported spending **most of their time indoors (95%)**.

To recruit participants, a **stakeholder mapping** was conducted across France, Spain, Germany, Italy, and other EU countries. This process identified research centres, organisations, and projects involved in air quality monitoring and environmental sensing. The most relevant contact person was selected for each institution based on expertise and relevance.

The recruitment strategy employed a combination of **purposive** and **snowball sampling**, supported by the following channels:

- **Direct email invitations** to identified stakeholders.
- **Peer dissemination**, encouraging recipients to forward the survey.
- **Social media promotion** via the official AMUSENS channels and Science For Change's accounts.

This mixed approach ensured broad yet targeted outreach to professionals and experts with direct or indirect experience in environmental sensing.

While the sample is **not statistically representative** of the general population, it was intentionally focused on participants capable of providing **informed, domain-relevant feedback**, in line with the exploratory and design-oriented purpose of this phase.

3.5.1.5 Data Analysis

The collected data (**N = 108**) underwent a **mixed-method analysis**, integrating quantitative and qualitative techniques to provide a comprehensive understanding of user requirements.

Quantitative Analysis:

Performed using **SPSS**, the analysis followed three sequential steps:

1. **Descriptive Statistics:** Generation of frequency and percentage distributions to profile respondents and establish baseline preferences.
2. **Bivariate Analysis:** Pearson's Chi-Square tests examined associations between key variables.
3. **Multivariate Analysis:** A binary logistic regression model identified predictors of the outcome variable.

Qualitative Analysis:

All open-ended responses were analysed using **qualitative content analysis**. Data were coded inductively to identify recurring themes, emerging needs, and key trust-related insights. Thematic grouping allowed interpretation of the underlying motivations behind user preferences.

3.5.2 Workshop Methodology

3.5.2.1 Purpose and Context

Building on the survey findings, a **series of three co-design workshops** were implemented within the framework of the **User-Centred Co-Design** approach adopted by AMUSENS. These participatory sessions aimed to translate user insights into concrete design specifications and usability criteria for the sensor prototypes.

Each workshop was tailored to the two main AMUSENS use cases and to a subsequent cross-validation phase at the European level:

- **Workshop 1 (Spain):** Focused on the *Personal Exposure* use case, engaging participants to explore real-world applications of gas exposure monitoring in everyday and occupational contexts.
- **Workshop 2 (Spain):** Centred on the *Breath Analysis* use case, addressing user perceptions, ethical aspects, and usability challenges of breath-based sensing.
- **Workshop 3 (European level):** Conducted online to validate and refine findings from the first two national workshops, ensuring generalisability and alignment across both use cases.

The present section details the methodology and outcomes of **Workshop 1 – Personal Exposure Use Case**, which sought to refine the design, usability, and acceptability of the personal gas exposure monitoring system.

Through structured, participatory activities, participants co-created and discussed:

- Potential real-world usage scenarios.
- Preferred sensor features and functionalities.
- Patterns of user interaction and data interpretation.
- Factors influencing trust, adoption, and behavioural change.

The insights generated from this workshop directly informed the subsequent stages of **sensor and platform development**, and provided a foundation for cross-validation in the European workshop.

3.5.2.2 Workshop Design and Protocol

The **2.5-hour co-design workshop** was held on **15 July 2025** at the Science For Change offices (Barcelona). It was structured around five interactive dynamics, each corresponding to a distinct phase of the Design Thinking process, using the **SFC Co-Design Toolkit** (Figure 3), a reusable co-creation kit designed as a sustainable alternative to paper materials. Tested across several European research projects, the hexagonal whiteboard pieces can be written on, erased, and reconfigured to build idea maps. The design is also inclusive for participants with colour vision difficulties.



Figure 3. SFC Co-Design Toolkit.

Objectives

- Understand participant motivations for assessing exposure.
- Optimise the user journey and data interaction flow.
- Define sensor placement, context of use, and ergonomic factors.
- Explore intuitive and actionable data interpretation.
- Identify factors affecting trust, adoption, and behavioural change.

Workshop Dynamics

- **Dynamic 1 – User Journey**
Participants mapped sensor interactions onto daily routines to explore *exposure contexts*, *alert mechanisms*, *decision-making*, and *data consultation habits*.
- **Dynamic 2 – Prototype**
Participants co-designed physical aspects of the sensor (portable vs. fixed), placement options (e.g., wall, wrist, pocket), and alert mechanisms (sound, vibration, light, or smartphone notification).
- **Dynamic 3 – Features**
Participants identified *must-have* and *nice-to-have* features, including physical attributes (size, robustness, transparency) and usability needs (battery life, connectivity, real-time display).
- **Dynamic 4 – Format**
The session focused on *data visualisation* (e.g., numeric, colour-coded, historical), *data access points* (sensor, app), and *communication of accuracy* (calibration, error margins).
- **Dynamic 5 – Trust**
Participants reflected on motivations and barriers to trust, identifying *trust builders* (e.g., certification, clear communication, official endorsement) and *sources of doubt* (e.g., inconsistent readings, poor interface understanding).

Recruitment and Sample

The workshop targeted a diverse group of participants, including citizens and key stakeholders, such as potential end-users who have an interest in monitoring gas exposure in their environments. Recruitment combined **direct invitations** and **public outreach**, launched on **18 June 2025**, using:

- Direct emails to **experts** and **stakeholders** in Catalonia and the Barcelona area, identified through the project's stakeholder mapping. The scope was limited to the region, as the workshop was in-person.
- Invitations to members of the **SFC Community** (a database of individuals interested in participating in research projects) and **SFC Newsletter subscribers**.
- **Public and Network Dissemination:** The invitation was shared with relevant civil society organizations (e.g., Platform for Air Quality, Catalan Association of Scientific Communication).

- **Social Media Campaign:** The call for participation was disseminated via the official AMUSENS social media channels, as well as the LinkedIn and Twitter (X) profiles of Science For Change.

The invitation clearly stated the context of the AMUSENS project, the workshop's activities, and logistical details (date, time, location). It also specified that **no specific prior knowledge was required**, encouraging participation from a broad public. A voucher was offered to all attendees as a token of appreciation for their time and contribution.

All invitations directed interested individuals to a Google Forms registration page. This form collected participants' email addresses for contact purposes and a limited set of sociodemographic details (age, gender, job position, and sector) to monitor and ensure a diverse sample. Acceptance of the GDPR disclaimer and the organization's privacy policy was a mandatory step to complete registration.

A total of **15 people registered** for the workshop. The session took place as planned on **July 15th** from 17:00 to 19:30 at the Science For Change offices in Barcelona, with a final attendance of **11 participants**.

Data Analysis

The qualitative data generated during the workshop (hexagons) was documented via high-resolution photographs. This raw data was then processed through a systematic **qualitative thematic analysis**.

- **Transcription:** Verbatim transcription of all written inputs by activity.
- **Coding:** Grouping and coding of responses by emergent categories.
- **Synthesis:** Cross-comparison between groups to identify consensus points, distinctive insights, and user priorities.

The consolidated results of this analysis are presented in **Chapter 4 (Results)**.

3.6 Breath Analysis Use Case

3.6.1 Survey Methodology

3.6.1.1 Objectives and rationale

The survey aimed to understand **perspectives, needs, and expectations** of potential users regarding a personal breath analysis monitoring system, with **particular attention to stress estimation, wellness tracking** (e.g., ketosis), and **early disease detection**. Specifically, it sought to:

- Identify target user profiles and relevant use-case scenarios.
- Elicit device feature preferences (format and functionality).
- Capture data interaction and interpretation preferences.

Findings were intended to prioritise topics for the subsequent co-design workshop and guide the user-centric development of the AMUSENS breath analysis application.

3.6.1.2 Questionnaire design

The survey instrument was an online questionnaire (see Annex 5. Preliminary questionnaire on breath analysis for the full questionnaire in English). The items were developed based on initial insights from WP4 and a review of the literature on user acceptance of health monitoring technologies. The survey was open from August 7 to October 8, 2025.

The questionnaire was formatted and distributed using Google Forms. To reach a diverse audience, including both the general public and healthcare professionals across Europe, the survey was translated into English, Spanish, French, German, Italian, and Greek. Translations were **partner-reviewed** for linguistic accuracy and cultural relevance (ICCS for Greek; other languages reviewed by SFC members proficient in each language).

Participants were first presented with a data protection disclaimer under the European Regulation 2016/679 (GDPR), which they had to accept to proceed.

3.6.1.3 Structure and content

The questionnaire explored user needs across the following **dimensions**:

- **Participant Profile and Experience:** Education level; professional role; prior knowledge of breath analysis; prior device use (e.g., alcohol breathalyser, ketone meter), including applications used.
- **Use Case Identification and Context:** Three primary scenarios—(1) fat loss/ketosis, (2) stress/fatigue/workout intensity, (3) respiratory infections. For each: ideal periodicity of use, preferred mode (self-administered at home vs. professional), and relevant contexts.
- **Device and Feature Preferences:** Physical device format; five-point importance ratings (*Not important* → *Essential*) for: ease of use, comfort, real-time feedback, data accuracy, smartphone connectivity, battery life, cost—assessed for each of the three use cases.
- **Data, Usability, and Trust:** Preferred calibration methods; qualitative data formats (e.g., colour scales, descriptive labels) to enhance understanding of outputs.
- **Motivations, Concerns, and Data Sharing:** Open-ended items on primary motivations and concerns for each use case; willingness to provide lifestyle information to contextualise results; interest in a cloud-connected device enabling data storage, personalised recommendations, and sharing with professionals (e.g., doctors, coaches).

3.6.1.4 Sample and recruitment

A total of **N = 37** respondents from various European countries completed the survey. A **targeted dissemination** strategy was used to reach both **general public** and **healthcare/wellness professionals**:

- Direct invitations to stakeholders in healthcare, wellness, and academia.
- Dissemination through project partners' networks.
- Snowball sampling, encouraging onward sharing.
- Social media promotion targeting communities interested in health technology, wellness, and medical innovation.

This purposive approach was designed to elicit deep, informed feedback from potential end-users and professionals. Given the **specificity** of the topic and **sample size (N=37)**, results are **not statistically representative**; rather, they constitute an expert-led **exploratory study** to guide the subsequent co-design phase.

3.6.1.5 Data analysis

A **mixed-methods** strategy combined quantitative statistics with qualitative content analysis.

Quantitative Analysis

Quantitative analysis was performed using SPSS and involved two main stages:

- **Descriptive Statistics:** Frequencies, percentages, and multiple-response frequencies.
- **Bivariate Analysis:** Pearson's Chi-Square and Spearman's rank correlation tests examined associations between key variables.

Methodological note: Due to the small, specialised sample (N=37) and purposive sampling, analyses are exploratory/descriptive. In several tests, Chi-Square assumptions were violated because of low expected cell counts; results are therefore interpreted as **indicative trends**, not generalisable inferences.

Qualitative Analysis

A qualitative content analysis for the open-ended responses was performed to identify recurring themes, emergent needs, and critical insights, especially regarding motivations and data-sharing concerns.

3.6.2 Workshop Methodology

3.6.2.1 Purpose and context



To build on the survey's quantitative insights, a qualitative co-design workshop was conducted, focusing on the Define and Develop phases of the Double Diamond methodology. The objective was to co-explore and define user needs and expectations for a breath analysis monitoring system by engaging potential end-users directly.

Format and logistics

The workshop was designed as a 2.5-hour online session, conducted via ZOOM on 16 September, 17:00–19:30. The session protocol was structured to validate and deepen the understanding of key assumptions derived from the survey, such as:

- Users are primarily motivated by proactive health and wellness management.
- Data privacy and clear, actionable interpretation are significant concerns.
- Trust depends heavily on scientific/clinical validation.

The workshop's **focus areas** were:

- Ideal sensor design and form factor.
- Prioritisation of core user requirements.
- User journey and behavioural impact.
- Engagement boundaries, especially around data sharing with professionals.

3.6.2.2 Protocol and activities

The workshop protocol built directly on survey insights and proceeded under the following **assumptions**:

- Proactive health/wellness is a key motivator.
- Simplicity, speed, and non-invasiveness are critical to adoption.
- Data privacy and actionable outputs are central.
- Scientific/clinical validation is a primary trust driver.

Objectives

- **Define** the ideal physical format (portable, fixed, mobile-connected), size/shape, and contextual use.
- **Prioritise** device features, distinguishing primary functionalities and secondary preferences.
- **Map** the end-to-end journey and anticipated behavioural effects of receiving health data.
- **Establish** acceptable levels of user engagement (calibration, lifestyle inputs, professional sharing).

Facilitation environment

Activities were facilitated using a series of **custom-designed interactive MIRO boards**, created by the SFC co-design team to manage the online collaboration, voting, and idea generation.

Five workshop dynamics

1. Ideal Sensor Design

Objective: Elicit preferences on usability and fundamental features across three scenarios.

Activities: Colour-coded Post-its covering: context of use (home, work, gym, clinic), frequency (daily, multiple times/day, weekly), preferred format (portable, stationary, mobile-connected; star-icon voting), data visualisation (numbers, graphs, colour-coded indicators).

2. User Requirements

Objective: Rank predefined features to establish a hierarchy of importance.

Activities: Individual ranking with numbered Post-its, followed by facilitator consolidation to produce group priorities; open discussion/refinement.

3. Prototyping

Objective: Co-design aesthetic and interactive elements.

Activities: Open brainstorming and voting on shape/size, colour palette, and interaction elements (buttons, lights, icons).

4. User Journey Map



Objective: Identify potential behaviour changes driven by the sensor's feedback over time.

Activities: Mapping the user lifecycle, noting thoughts/emotions/challenges and capturing "Opportunity/Change" moments where data may trigger habit change.

5. Engagement and Scenario Selection

Objective: Assess commitment and preferred scenario.

Activities: Emoticons to express comfort with calibration, lifestyle data entry, app use, professional data sharing; final single-scenario vote with written rationale and note of any change from the session start.

3.6.2.3 Sampling and recruitment

Target profiles: General public and key stakeholder groups with a **specific interest in health and wellness monitoring**, ensuring diverse user profiles.

Recruitment Strategy and Process

- **Direct email invitations** to contacts identified via project stakeholder mapping and the SFC Community.
- **Social media campaign** via official AMUSENS channels, relevant health/technology networks, and SFC social media.
- **Incentive:** Voucher offered to all attendees as a token of appreciation.
- **Final sample:** 16 registered; **8 participants attended** the online session (ZOOM; 16 September, 17:00–19:30).

3.6.2.4 Data capture and analysis

All MIRO content (Post-its, ranked lists, journey maps, co-designed concepts) was exported and archived. A **qualitative thematic analysis** followed:

- **Data Transcription:** Verbatim transcription of written inputs per activity.
- **Thematic coding:** First by activity, then inductive coding into emergent categories/themes (e.g., "Need for professional interpretation", "Privacy is paramount", "Calibration must be simple").
- **Synthesis:** Cross-theme integration to produce consolidated findings, including a prioritised feature list, actionable data-visualisation recommendations, and a comprehensive user journey map.

3.7 European Validation Workshop

3.7.1 Purpose and position in the methodology

This final workshop constituted the primary activity of the **Deliver** phase within the Double Diamond framework. Its purpose was to **validate, refine, and contrast** the user requirements identified in the two local workshops (Spain: Personal Exposure and Breath Analysis) by engaging a **broader, pan-European audience**.

3.7.2 Session design and objectives

The two-hour online workshop, titled "**Understanding your environment & listening to your body: Shape the ideas behind the sensors of tomorrow,**" took place on 16 October from 15:00 to 17:00. The session was conducted using ZOOM for video conferencing and MIRO as the interactive collaboration platform.

3.7.2.1 Primary objectives

- **Validate and deepen** understanding of user needs, motivations, and expectations collected in the local workshops.
- Identify **convergences** (overlaps) and **divergences** (case-specific needs) between the Personal Exposure and Breath Analysis use cases.

- Gather **final feedback** to inform **technical development** and **future implementation strategies**.

3.7.2.2 Structure

Participants were assigned to two parallel groups, one per use case, each with dedicated facilitators and a custom MIRO board aligned to the workshop dynamics.

3.7.2.3 Participants and recruitment

Target profile

Members of the general public and key stakeholders from a wide range of European countries to ensure diverse, pan-European perspectives and to test the generalizability of findings from the local workshops.

Recruitment strategy

- **Direct email invitations** to international contacts from the project's stakeholder mapping and the SFC Community.
- **Consortium partner dissemination** through local/professional networks to broaden reach across Europe.
- **Social media campaign** via official AMUSENS channels and SFC profiles.

Final sample: **N = 22** participants from various European countries attended the online session.

3.7.3 Workshop dynamics

The **2-hour** session comprised **five interactive dynamics**, mirrored across both groups and facilitated via the custom MIRO boards, created by the SFC co-design team:

- **Dynamic 1 — User Requirements**

Activities:

Open **brainstorm** of ideal sensor features.

Voting to prioritise a predefined list of **nine key requirements**.

Identification of **trust-building factors**.

(Breath Analysis group only): **Sentiment** on key engagement actions.

- **Dynamic 2 — Empathy (User Journey Map)**

Activities:

Guided **end-to-end journey mapping** to capture anticipated **emotions, thoughts, and challenges** at each phase; identification of **opportunity/behaviour-change moments**.

- **Dynamic 3 — Validation**

Activities:

Voting on **key conclusions** and **summary statements** generated from the two local workshops (Yes / Neutral / No), to confirm or contest prior findings.

- **Dynamic 4 — Contrast**

Activities:

Structured **comparison** of **convergences** (shared requirements) and **divergences** (unique needs) between **Personal Exposure** and **Breath Analysis**.

- **Dynamic 5 — Final Discussion**

Activities:

Plenary within each group organised around three guiding questions to consolidate **technical priorities, implementation challenges, and anticipated behavioural impacts**.

3.7.4 Data capture and analysis



All MIRO artefacts (free-text Post-its, star/dot votes, emoji feedback, journey maps) were exported and archived. Analysis followed a **qualitative thematic approach** consistent with previous phases:

- **Transcription:** Verbatim transcription of contributions per dynamic and use case.
- **Thematic coding:** First by activity and use case, then inductive coding into emergent categories and key themes (e.g., trust drivers, usability priorities, cross-case overlaps).

Synthesis: Cross-group comparison to identify **consensus**, **key differences**, and the **consolidated, validated requirements**.

Chapter 4 Results

This chapter presents the **consolidated findings** derived from the data collection and participatory activities described in the previous section. The results are **organised by use case (Personal Exposure and Breath Analysis)**. Each subsection begins with the **quantitative survey outcomes**, which establish a foundational understanding of user profiles, needs, and expectations. These are followed by the **qualitative insights** generated through the **co-design workshops**, which provide contextual depth, user-driven interpretation, and **actionable recommendations** to inform the sensor design and subsequent development phases.

4.1 Personal Exposure Use Case

4.1.1 Results of the survey

This section presents the results of the online survey conducted for the *Personal Exposure* use case (**N = 108 respondents**). The analysis proceeds from the general sample profile to the exploration of motivations, preferred features, and predictive factors of user trust in data reliability.

4.1.1.1 Sample Profile

The respondent base for this survey was characterized by a high level of academic education and expertise. An overwhelming **99.1% (N=107) of respondents reported having a university-level education**.

A key variable for this study was the self-reported level of knowledge regarding Indoor Air Quality (IAQ) monitoring (Figure 4). The sample was not a general public audience but trended towards expertise:

- **Specialist in the field:** 24.1%
- **Familiar:** 33.3%
- **Basic:** 25.0%
- **None:** 17.6%

This indicates a highly informed and engaged sample.

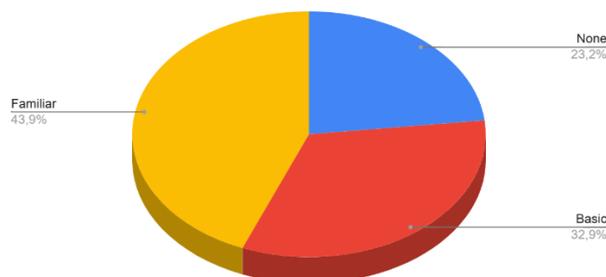


Figure 4. Level of knowledge/experience with IAQ monitoring

In terms of context, **94.4% of respondents reported spending most of their time indoors**, confirming the contextual relevance of the personal exposure use case.

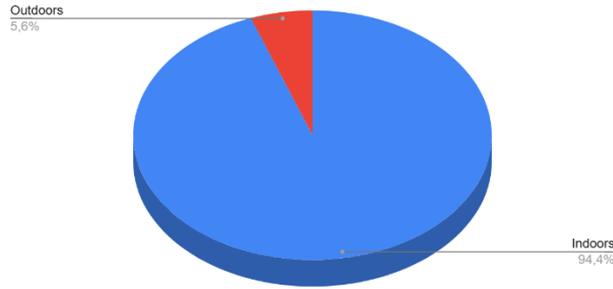


Figure 5. Time predominantly spent Outdoors and Indoors

4.1.1.2 Key Motivations, Contexts, and Features

Multiple-response analysis indicates that **research purposes (69.5%)** and **health issues (65.7%)** were the primary motivations for interest in exposure monitoring, followed by **curiosity (50.5%)**. Secondary motivations included *desire to implement changes (32.4%)*, *organizational requirements (17.6%)*, and *public demand (16.7%)*.

Table 1. Reasons for interest in assessing exposure to gases

Category	Percent of Cases (%)
Research purposes	69.5%
Health issues	65.7%
Curiosity	50.5%
A desire to implement changes	32.4%
Organization's requirements	17.6%
Public demand	16.7%

4.1.1.3 Contexts of Use

When asked to identify environments with the highest perceived need for gas exposure monitoring, respondents prioritised **workplaces (74.8%)** and **homes (70.1%)**, followed by **public transport (53.3%)** and **schools (51.4%)**.

Table 2. In which of the following settings do you perceive the highest need for monitoring exposure to gases?

Category	Percent of Cases (%)
Workplace	74.8%
Home	70.1%
Public transport	53.3%
Schools	51.4%
Hospitals	38.9%
Leisure facilities	31.5%

4.1.1.4 Preferred Device and Key Features

Regarding device preferences, a **wearable format (44.4%)** was the most popular choice, followed by fixed (27.8%) and mobile-integrated (25.9%) devices.

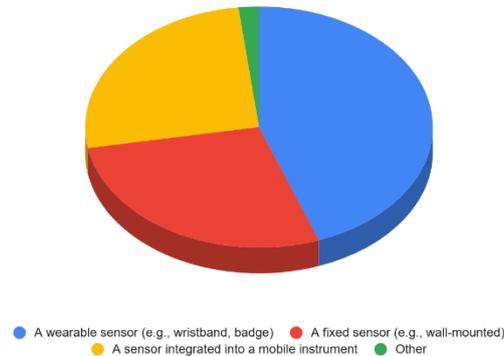


Figure 6. Preferred type of monitoring device

In terms of technical requirements, the most valued features were: **"Real-time data" (74.8%)**, "Data transmission to a mobile/PC" (64.5%), and "High accuracy" (61.7%).

Table 3. Most relevant device features (Multiple-response table of characteristics)

Category	Percent of Cases (%)
Real-time data	74.8%
Data transmission to a mobile/PC	64.5%
High accuracy	61.7%
Gas identification	60.7%
Portability	58.9%
Low cost	53.3%
Alert system	51.4%
Ease of use	46.7%
Low maintenance	42.1%
Long-term (battery) autonomy	38.3%

4.1.1.5 Exploring Key Relationships (Hypothesis Testing)

To move beyond simple descriptions, bivariate analyses (crosstabulations using Pearson's Chi-Square) were conducted to test initial hypotheses about the relationships between user profiles and preferences.

Hypothesis 1: A user's level of expertise will influence their preferred device type.

- **Result:** *Not supported* ($p = .536$).
- **Conclusion:** No statistically significant relationship was found between a user's level of knowledge and their preferred device type. Device preference is therefore a **universal usability factor**, independent of technical expertise.

Table 4. Crosstabulation between Level of Knowledge and Preferred Type of Monitoring Device, with Chi-Square Test Results

		Preferred type of monitoring device			
		A wearable sensor	A fixed sensor	A sensor integrated...	Other
Level of knowledge	None	10 (52.6%)	6 (31.6%)	3 (15.8%)	0 (0.0%)
	Basic	11 (40.7%)	7 (25.9%)	9 (33.3%)	0 (0.0%)
	Familiar	19 (52.8%)	10 (27.8%)	6 (16.7%)	1 (2.8%)
	Specialist in the field	8 (30.8%)	7 (26.9%)	10 (38.5%)	1 (3.8%)
Total		48 (44.4%)	30 (27.8%)	28 (25.9%)	2 (1.9%)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.979	9	.536

Note: df = degrees of freedom; Asymp. Sig. (2-sided) = Asymptotic Significance (2-sided), which represents the p-value.

Hypothesis 2: Users motivated by "Health issues" will have a different expectation for the duration of monitoring.

- **Result:** *Supported* ($p = .017$).
- **Conclusion:** Participants motivated by health issues were significantly more likely to prefer **continuous monitoring (60.6%)** than those without health-related motivation (**36.1%**). This indicates a clear **demand for sustained monitoring** among health-focused users.

Table 5. Crosstabulation between Reason: Health Issues and Longest Period Willing to Use the Monitoring System, with Chi-Square Test Results

		Longest period willing to use the monitoring system			
		One day	One week	One month	Continuously
Reason: Health issues	No	4 (11.1%)	13 (36.1%)	6 (16.7%)	13 (36.1%)
	Yes	3 (4.2%)	13 (18.3%)	12 (16.9%)	43 (60.6%)
Total		7 (6.5%)	26 (24.3%)	18 (16.8%)	56 (52.3%)

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.198	3	.017

Note: df = degrees of freedom; Asymp. Sig. (2-sided) = Asymptotic Significance (2-sided), which represents the p-value.

4.1.1.6 Predictive Model for Trust: Concern for Data Reliability

Finally, to understand the critical issue of trust, a **binary logistic regression** model was constructed. The model aimed to identify which factors best predict whether a user will be **"Concerned about the reliability of the data"** (Yes/No).

The model tested the predictive power of 'Level of knowledge', 'Reason: Health issues', and 'Preferred form of information delivery'. The overall model was statistically significant (Chi-Square = 16.518, $p = .001$) and correctly classified **66.3% of cases**, improving substantially over random classification (50%).

Table 6. Omnibus Tests of Model Coefficients

	Chi-square	df	Sig.
Step 1	16.518	4	.001

Note: df = degrees of freedom; Sig. = Significance (p-value), indicating the statistical significance of the model.

Table 7. Model Summary, showing the Nagelkerke R-squared value

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	127.360	.142	.190

Note: -2 Log likelihood is a measure of model fit (lower values indicate a better fit); Cox & Snell R Square and Nagelkerke R Square are pseudo R-squared values that estimate the proportion of variance in the dependent variable explained by the model.

Table 8. Classification Table, showing that the model correctly classifies 66.3% of participants

Observed		Predicted	
		Concern about reliability: No	Concern about reliability: Yes
Step 1	Concern: No	31	23
	Concern: Yes	13	38

Two variables emerged as significant predictors:

- **Level of Knowledge:** Greater expertise was associated with *lower concern for reliability*. Participants classified as "Familiar" ($p = .009$) and "Specialist" ($p = .025$) were significantly less likely to express concern compared to those with no expertise.
- **Preferred Form of Delivery:** Participants who preferred data *interpreted by an expert* ($p = .021$) were **3.6 times more likely** to express concern about reliability than those preferring on-sensor data.

Conclusion: This model provides a clear psychological profile of the "concerned" user. **Concern** is highest among **non-experts** and those who **simultaneously desire expert interpretation**. This suggests that the desire for expert help is driven by a fundamental lack of trust in the raw data and their own ability to interpret it. Therefore, building trust for this group requires not just an accurate sensor, but a clear, supportive, and possibly expert-validated interpretation framework.

Table 9. Variables in the Equation, showing the significant predictors, Exp(B) (Odds Ratio), and p-values

Variable	B	S.E.	Sig.	Exp(B) (Odds Ratio)
Level_knowledge (Ref: None)				
Level_knowledge(1) (Basic)	-1.139	.620	.066	.320

Level_knowledge(2) (Familiar)	-1.826	.701	.009	.161
Level_knowledge(3) (Specialist)	-1.543	.689	.025	.214
Reason_Health(1) (Ref: No)	.558	.441	.206	1.747
Delivery_form (Ref: On-sensor)				
Delivery_form(1) (Mobile app)	.630	.616	.306	1.878
Delivery_form(2) (Interpreted)	1.282	.555	.021	3.603
Constant	.177	.558	.752	1.194

Note: B = Unstandardized coefficient (Log-odds); S.E. = Standard Error (of the coefficient); Sig. = Significance (p-value); Exp(B) = Odds Ratio (exponentiated coefficient).

4.1.1.7 Summary of Quantitative Findings for Personal Exposure

The quantitative results for the *Personal Exposure* use case (N = 108) reveal a **highly educated and knowledgeable user base** primarily motivated by **health protection** and **research interests**.

The **preferred environments** for monitoring are **workplaces and homes**, with a **wearable sensor** as the most favoured format. Users prioritise **real-time data**, **connectivity**, and **accuracy** as essential features.

Statistical testing showed that **expertise does not affect device preference**, while **health-motivated users demand continuous monitoring**.

Finally, the **predictive model for trust** indicates that **non-expert users** and those who prefer **expert interpretation** are **most concerned about data reliability**. This underscores the importance of **clear communication**, **calibration transparency**, and **expert-endorsed interpretation** in the final system design.

These insights establish a robust baseline for the co-design workshops, where these priorities and trust conditions were further explored.

4.1.2 Results of the co-design Workshop

A 2.5-hour in-person co-design workshop was conducted in Barcelona with **11 participants**, facilitated by Science For Change (SFC) using a participatory co-design methodology. The objective was to explore user expectations, behavioural responses, and trust conditions related to a personal gas-exposure sensor. The workshop combined scenario-based discussions, physical prototyping, and collective reflection exercises to ground the AMUSENS concept in realistic daily contexts.

4.1.2.1 Overview and Key Insights

The session provided rich, user-driven evidence to guide the sensor's functional and interface design. Participants envisioned how a personal exposure sensor could integrate into daily life, what actions it should trigger, and how users would interact with its data.

The consolidated conclusions are summarised below:

- **Portable, personal, and actionable**

Users expressed a clear preference for **portable and wearable sensors** over stationary devices. They envisioned discreet, comfortable accessories (e.g., wristbands, necklaces, phone-linked modules) enabling constant monitoring across different environments (e.g., kitchens, garages, workplaces). Crucially, users expect **actionable alerts**, not raw data—specific prompts such as “Open a window” or “Stop spraying” that translate detection into immediate safety behaviour.

- **Simple at a glance, rich on demand**

The most valued feature was **simplicity in data display**, particularly the “traffic light” colour system for instant comprehension. However, users also want **layered access** to deeper information—

specific pollutants, trends, or historical data—via an app interface. This flexibility ensures accessibility for non-technical users while satisfying more advanced needs for analysis and tracking.

- **Trust through transparency and validation**

Trust was consistently cited as the decisive factor for adoption. Users demand **certified validation**, **transparency about accuracy**, and **control over their data**. They expect to see a declared margin of error, self-calibration options, and visible proof of consistency. Conversely, poor reliability, inconsistent readings, or opaque data handling would immediately erode confidence.

- **System as a connected safety net**

Beyond individual use, participants saw value in a **connected ecosystem**—where alerts can be shared with family members, caregivers, or even community networks. This social dimension transforms the device from a standalone sensor into an integrated element of a **collective safety infrastructure**.

These insights established the user-centred foundations for subsequent sensor and app design. The findings were directly integrated into the requirements specification for WP7 (multi-pixel sensor processing) and WP8 (multi-pixel sensor testing), ensuring that usability, reliability, and transparency are built into both hardware and interface development.

4.1.2.2 Dynamic 1: User Stories

This activity mapped potential user journeys to understand how a gas alert system would function in everyday life. Participants developed scenarios for multiple personas, identifying contexts of use, reactions to alerts, and desired system behaviours.

At a glance:

- **Users** instinctively **respond to alerts** by ventilating or reducing exposure.
- **Multi-modal alerts** (sound, vibration, light, mobile) are essential for **safety**.
- **Remote alerts** for family members enhance perceived **security** and **trust**.
- Users seek **clarity** on detected gases and context (indoor vs. outdoor).

Key findings:

- **Multi-modal alerts are essential.** The optimal channel depends on context (e.g., visual/mobile alerts during cooking; audible/vibration alerts for smoke or chemical exposure).
- **Ventilation is the immediate reflex.** Common responses include opening windows, lowering heat, halting the activity, or using protective equipment.
- **Remote safety net matters.** Users want alerts to notify family or trusted contacts when they are away.
- **Scope questions surfaced.** Participants asked whether the sensor should detect only natural gas or a broader range of household pollutants (VOCs, combustion products).
- **Contextual insight desired.** Differentiating between indoor and outdoor sources helps users decide whether to ventilate or isolate the space.

Design implications:

- Provide **multi-channel alerting** (sound, light, vibration, mobile) with contextual defaults.
- Include **action prompts** linked to specific detections (e.g., “Open window,” “Reduce heat,” “Use PPE”).
- Enable **configurable escalation** and **remote notifications** for household or community contacts.
- Integrate **source differentiation** (indoor vs. outdoor) within the app interface to guide proper response.

Conclusion:

This dynamic directly informed the development of adaptive alert systems within the AMUSENS platform, ensuring context-sensitive notifications and responsive design. The user behaviours observed were translated into the sensor–app communication logic defined under WP7 and WP8.

4.1.2.3 Dynamic 2: Prototype

This session focused on physical conceptualisation, where participants translated scenarios into tangible product ideas. Two primary device types emerged: **portable sensors** and **fixed devices** for high-risk areas.

At a glance:

- Clear **preference for portable/wearable** sensors (8 votes) over fixed units (2 votes).
- **Preferred form** factors: smartwatch, necklace, or keychain-type device.
- **Fixed sensors** considered **useful** in **specific locations** (kitchen, garage, boiler room).
- **Portability** linked to continuous personal **protection** and **configurable alerts**.

Key findings:

- **Portable sensors** are expected to act as **personal companions**—compact, discreet, and aesthetically aligned with daily use. Users envision **seamless integration with smartphones and wearables**, enabling real-time alerts and continuous data logging.
- Portability is associated with **contextual awareness** and **mobility across environments**, reinforcing the value of **personalised exposure monitoring**.
- **Fixed sensors** are viewed as **complementary solutions**, appropriate for **static and high-risk zones** (e.g., kitchens, garages, boiler rooms) where persistent monitoring enhances safety.
- Users clearly differentiate the purpose of each format: **portable devices for individual protection and situational awareness**, and **fixed devices for environmental safeguarding in defined locations**.

Design implications:

- Prioritise **wearable design** as the main product line; use fixed sensors as optional complements.
- Implement **configurable, multi-modal alerts** (sound, vibration, light) with automatic data transfer to the app.
- For fixed models, integrate **traffic-light indicators** and allow them to act as local data hubs for household monitoring.

Conclusion:

The outcomes from this dynamic shaped the physical architecture and modularity strategy of the AMUSENS system, supporting both mobile personal devices and static environmental units. These distinctions were reflected in the system integration plan linking WP6 and WP7.

4.1.2.4 Dynamic 3: Features

Participants collaboratively defined the key functionalities and universal principles that the sensor and its digital interface should embody.

At a glance:

- Portable sensors must be **small, durable, and customisable**.
- Fixed sensors must be **aesthetic, clear, and actionable**.
- Universal principles: **accessibility, affordability, and transparency**.

Key findings:

- **Portable devices** should combine **robustness and discretion**, featuring **long-lasting rechargeable batteries** (≥1 week) and **customisable alert settings** to adapt to different user contexts.
- Participants strongly emphasised **data privacy** and the ability to **track pollutant history** through clear, visual records.
- For **fixed sensors**, participants prioritised **high-quality, “Apple-style” design** and **action-oriented advice** (e.g., “Tips to improve air quality”) that translate data into practical guidance.
- Across both formats, **inclusive usability** (accessible for all ages and abilities) and **data centralisation in a single mobile hub** were identified as **essential system requirements**.

Design implications:

- Deliver **dual-layer data**: simple aggregated indicator + detailed pollutant breakdown.
- Ensure **privacy-by-design** with local data control and historical visualisation.
- Apply **inclusive design standards** (e.g., colour-vision safe palettes, intuitive UI).
- Integrate **AI-based recommendations** transparently, avoiding “black-box” logic.

Conclusion:

This dynamic directly influenced both hardware (sensor compactness, durability) and software (app interface and data architecture) specifications. These user-derived principles were operationalised in the design documentation transferred to WP7 and WP8.

4.1.2.5 Dynamic 4: Format

This activity defined how environmental data should be presented, accessed, and interpreted by the user—ensuring clarity, trust, and guidance.

At a glance:

- Layered display combining **simple traffic-light index** and **detailed pollutant data**.
- **Mobile app as primary interface**, with minimal on-device indicators.
- **Action-oriented feedback** guiding user behaviour.

Key findings:

- Participants preferred a **layered UX**, combining an **immediate, intuitive overview** (colour-coded safety index) with **deeper data** accessible through the app as needed.
- **Contextual differentiation** (e.g., **indoor vs. outdoor** sources) was considered essential for meaningful interpretation and correct user action.
- Users expect **real-time visibility** on air quality, **complemented by weekly summaries** to support reflection and behavioural learning.
- Crucially, users demand not only **data** but **actionable guidance**—clear, practical suggestions for what to do in response to detected conditions.
- Participants stressed the importance of **transparent system status**, including **confidence levels, calibration alerts, and operational indicators**, to maintain trust and ensure responsible use.

Design implications:

- Implement a **tiered data architecture**: quick safety indicator → detail view → suggested action.
- Display **confidence margins and timestamps** to build transparency.
- Add **automated summaries and “while-away” notifications** to support user engagement.

Conclusion:

This dynamic informed the user-interface flow of the AMUSENS companion app. The emphasis on clarity, reliability, and contextual guidance directly shaped WP8’s testing framework for user validation and performance evaluation.

4.1.2.6 Dynamic 5: Trust

This session addressed the foundational and advanced elements of user trust in health and environmental monitoring technologies.

At a glance:

- **Certification and validation** are non-negotiable trust enablers.
- Users demand **transparency, self-calibration, and control over data**.
- Trust grows through **official oversight and credible branding**; it is destroyed by inconsistency or lack of proof.

Key findings:

Participants articulated a three-tier trust framework:

- **Foundational** – official EU certification, calibration capability, transparent margin of error, clear data ownership.

- **Enhancing** – medical-grade classification, official inspection routines, visible updates, and retail availability in trusted outlets.
- **Eroding** – unverified data, unstable performance, or excessive irrelevant alerts (“alert fatigue”).

Design implications:

- **Publish validation evidence** (certification, reference data, calibration methodology).
- Embed **self-diagnosis and calibration guidance** directly in the app.
- Uphold **privacy-by-design principles** and provide clear data-use statements.

Conclusion:

Trust was identified as the critical determinant of user adoption. The findings were translated into the AMUSENS validation and certification roadmap, ensuring that trust mechanisms are embedded across all subsequent development WPs.

4.1.2.7 Summary

The Personal Exposure co-design workshop confirmed that users expect a **wearable, intelligent, and transparent** environmental monitoring system that protects them in real-world contexts. They prioritise simplicity, trustworthiness, and actionable guidance over technical complexity.

These findings have been systematically translated into the **functional, interface, and ethical design requirements** guiding the technical development of AMUSENS within WP7 (multi-pixel sensor processing) and WP8 (sensor validation). Together, they ensure that the platform advances technological excellence while remaining grounded in **user trust, societal value, and real-life usability**.

4.2 Breath Analysis Use Case

4.2.1 Results of the survey

This section details the findings from the online survey conducted for the Breath Analysis use case (**N=37 respondents**). Due to the small and specialized nature of the sample, the analysis focuses on identifying key priorities, preferences, and exploratory trends rather than making broad statistical generalizations.

4.2.1.1 Sample Profile

The respondent group for this survey represents a highly specialized cohort. All participants (100%) reported having a university-level education, and the professional roles were dominated by **"Researchers/Clinicians" (68.8%)**, followed by "General Public / potential user" (18.8%) and "Technology Developers/Engineers" (12.5%). Five cases were missing for this item.

Table 10. Current Professional Role (Grouped)

Category	Frequency (N)	Percent (%)	Valid Percent (%)
Researcher/Clinician	22	59.5	68.8
Technology Developer/Engineer	4	10.8	12.5
General Public / potential user	6	16.2	18.8
Total Valid	32	86.5	100.0
Missing System	5	13.5	
Total	37	100.0	

However, despite this high level of general expertise, specific knowledge regarding *breath analysis* technology was low. A significant majority (**80.6%**) rated their knowledge as either **"None" (52.8%)**

or **"Basic" (27.8%)**. Only a small fraction identified as "Familiar" (13.9%) or "Specialist/Expert" (5.6%).

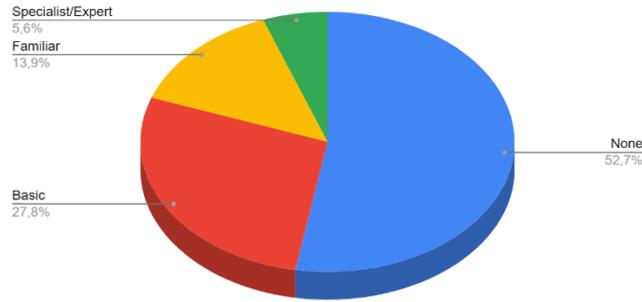


Figure 7. Knowledge of Breath Analysis

This was further corroborated by the finding that **67.6% had never used a breath analysis device before**.

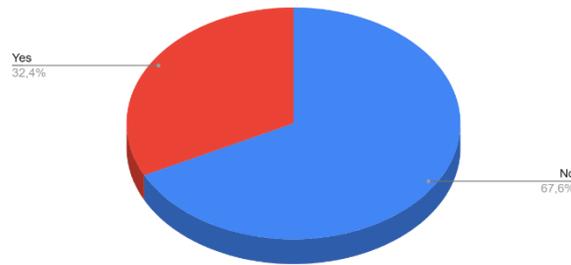


Figure 8. Previous Experience with Breath Analysis Devices

This combination defines a unique user profile: the **"Expert Novice."** These are users with high scientific literacy who demand robust evidence but are simultaneously first-time users of this specific technology, requiring a clear and intuitive user experience.

4.2.1.2 Key Priorities: Use Cases, Context, and Accuracy

The survey clearly identified the most compelling applications and the critical requirements for user adoption.

- **Dominant Use Case:** One application stood out significantly: **"Diet performance/fat loss"** was selected as a promising use case by **80.6%** of respondents. Secondary interests included "Personal health tracking" (45.2%) and "Disease detection" (41.9%), while fitness and stress monitoring were seen as niche applications for this sample.

Table 11. Most Promising Use Cases (Multiple Response Table)

Category	Percent of Cases (%)
Diet performance/fat loss	80.6%
Personal health tracking	45.2%
Disease detection	41.9%
Fitness/workout performance	9.7%

Stress/fatigue monitoring	9.7%
---------------------------	------

- Context-Dependent Mode of Use:** User preference for how to use the device varied dramatically by application.
 - For *wellness* applications (Fat Loss, Stress), there was an overwhelming preference for **Self-monitoring (83.3%)**.
 - For *medical* applications (Infection Detection), this reversed, with a majority (**57.1%**) preferring to use the device **With a professional**. This highlights a clear user distinction: empowerment for wellness, professional guidance for medical diagnostics.

Table 12. Crosstabulation between Application: Fat Loss and Preferred Mode of Use

		Preferred Mode of Use	
		Self-monitoring	With a professional
Application: Fat Loss	Interested	25 (83.3%)	5 (16.7%)
Total		25 (83.3%)	5 (16.7%)

Table 13. Crosstabulation between Application: Stress and Preferred Mode of Use

		Preferred Mode of Use	
		Self-monitoring	With a professional
Application: Stress	Interested	5 (83.3%)	1 (16.7%)
Total		5 (83.3%)	1 (16.7%)

Table 14. Crosstabulation between Application: Infection and Preferred Mode of Use, with Chi-Square Test Results (percentages by row, N = 14 valid cases)

		Preferred Mode of Use	
		Self-monitoring	With a professional
Application: Infection	Interested	6 (40.0%)	8 (57.1%)
Total		6 (40.0%)	8 (57.1%)

- Primacy of Accuracy (especially for Medical Use):** Accuracy was identified as the single most significant user concern overall. This was particularly stark for the medical application: **83.8%** rated accuracy as **"Essential"** for infection detection. This reinforces the link between medical applications and the need for the highest standards of reliability, likely driving the preference for professional involvement.



Table 15. Importance of Accuracy for Infection

Category	Frequency (N)	Percent (%)
Not important	0	0.0
Slightly important	0	0.0
Moderately important	0	0.0
Very important	4	10.8
Essential	31	83.8
Total	37	100.0

- Main User Concerns:** Echoing the importance of accuracy, the analysis of user concerns showed "**Accuracy/Reliability**" as the top concern, cited by **85.3%** of cases. The second major concern was the "**Misuse of Health Data**" (**61.8%**), highlighting the critical need for robust data governance. Practical issues like "Cost" (44.1%) and "Maintenance/Calibration" (35.3%) were relevant but secondary.

Table 16. Main Concerns (Multiple Response Table)

Category	Percent of Cases (%)
Accuracy/Reliability	85.3%
Misuse of Health Data	61.8%
Cost	44.1%
Maintenance/Calibration	35.3%
Discomfort/Hygiene	32.4%
Privacy/Data Sharing	26.5%

4.2.1.3 Exploring Key Relationships (Hypothesis Testing)

Several bivariate analyses were conducted to explore potential relationships between user characteristics and preferences. However, due to the small sample size (N=37), these results should be interpreted as **exploratory trends rather than statistically significant findings**. Many tests violated the assumptions of the Chi-Square test due to low expected cell counts.

Hypothesis 1: Users with greater knowledge of breath analysis will express lower concern for accuracy.

- Result:** *Rejected* ($p = .582$).
- Finding:** No statistically significant relationship was observed between respondents' self-reported knowledge and their concern for accuracy ($\chi^2(3)=1.956$, $p=.582$). Concern for accuracy remained consistently high across all knowledge levels, indicating that this factor is universal rather than dependent on expertise.
- Conclusion:** Regardless of their familiarity with breath analysis, all users demonstrate a strong expectation for high accuracy and reliability. This suggests that precision is perceived

as a **baseline requirement** rather than a differentiating feature, reinforcing the need for transparent validation and error reporting in the sensor design.

Table 17. Crosstabulation between Knowledge of Breath Analysis and Concern About Accuracy, with Chi-Square Test Results

		Concern_Accuracy	
		Not Concerned	Concerned
Knowledge	None	5 (26.3%)	14 (73.7%)
	Basic	1 (10.0%)	9 (90.0%)
	Familiar	1 (20.0%)	4 (80.0%)
	Specialist/Expert	1 (50.0%)	1 (50.0%)
Total		8 (23.5%)	26 (76.5%)

(Note: Percentages by row. N=34 valid cases).

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.956a	3	.582

(a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .47.)

Note: df = degrees of freedom; Asymp. Sig. (2-sided) = Asymptotic Significance (2-sided), which represents the p-value.

Hypothesis 2: Prior experience with breath analysis devices reduces concerns about accuracy, cost, or privacy.

- **Result:** *Rejected* ($p = .729$; $p = .536$; $p = .947$).
- **Finding:** No statistically significant relationships were identified between previous device use and user concerns related to accuracy/reliability ($\chi^2(1)=.120$, $p=.729$), cost ($\chi^2(1)=.383$, $p=.536$), or privacy/data sharing ($\chi^2(1)=.004$, $p=.947$). These concerns persisted independently of prior experience.
- **Conclusion:** Concerns regarding measurement reliability, data protection, and affordability are **consistent across all user groups**, including those with previous exposure to similar devices. This indicates that **familiarity does not mitigate caution**—users require tangible evidence of accuracy, transparent data governance, and clear communication of value to build and maintain trust.

Table 18. Crosstabulation between Previous Device Use and Concern About Accuracy, with Chi-Square Test Results

		Concern_Accuracy	
		Not Concerned	Concerned
UsedDevice_n	No	4 (20.0%)	16 (80.0%)

	Yes	3 (25.0%)	9 (75.0%)
Total		7 (21.9%)	25 (78.1%)

(Note: Percentages by row. N=32 valid cases).

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.120a	1	.729

(a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 2.63.)

Note: df = degrees of freedom; Asymp. Sig. (2-sided) = Asymptotic Significance (2-sided), which represents the p-value.

Table 19. Crosstabulation between Previous Device Use and Concern About Cost, with Chi-Square Test Results

		Concern_Cost	
		Not Concerned	Concerned
UsedDevice_n	No	14 (56.0%)	11 (44.0%)
	Yes	6 (66.7%)	3 (33.3%)
Total		20 (58.8%)	14 (41.2%)

(Note: Percentages by row. N=34 valid cases).

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.383a	1	.536

(a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.29.)

Note: df = degrees of freedom; Asymp. Sig. (2-sided) = Asymptotic Significance (2-sided), which represents the p-value.

Table 20. Crosstabulation between Previous Device Use and Concern About Privacy, with Chi-Square Test Results

		Concern_Privacy	
		Not Concerned	Concerned
UsedDevice_n	No	19 (76.0%)	6 (24.0%)
	Yes	6 (75.0%)	2 (25.0%)
Total		25 (75.8%)	8 (24.2%)

(Note: Percentages by row. N=33 valid cases).

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.004a	1	.947

(a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 1.94.)

Note: df = degrees of freedom; Asymp. Sig. (2-sided) = Asymptotic Significance (2-sided), which represents the p-value.

Hypothesis 3: Users with higher knowledge levels will attribute greater importance to measurement accuracy.

- **Result:** *Rejected* ($p = .018$, $p = .916$).
- **Finding:** Spearman’s correlation analysis revealed no significant relationship between respondents’ self-assessed knowledge of breath analysis and the importance they assigned to measurement accuracy. The prioritisation of accuracy remained uniformly high across all knowledge categories.
- **Conclusion:** The perceived importance of accuracy is **independent of expertise or familiarity with the technology**. This confirms that precision and reliability are **non-negotiable design requirements** for both professional and general users, reinforcing the need for validated calibration, transparent performance reporting, and consistent quality assurance throughout the AMUSENS system.

Table 21. Spearman Correlation between Knowledge of Breath Analysis and Average Importance of Accuracy

		Knowledge of Breath Analysis	Average Importance of Accuracy
Spearman's rho	Knowledge of Breath Analysis	Correlation Coefficient	1.000
		Sig. (2-tailed)	.
		N	36
	Average Importance of Accuracy	Correlation Coefficient	.018
		Sig. (2-tailed)	.916
		N	36

Note: Correlation Coefficient = Spearman's rho correlation coefficient, measuring the strength and direction of association between two ranked variables; Sig. (2-tailed) = Significance (p-value) for a two-tailed test; N = Number of cases (sample size).

Hypothesis 4: Interest in the “Diet Performance / Fat Loss” application will vary by professional role.

- **Result:** *Rejected* ($p = .779$).
- **Finding:** No statistically significant differences were found across professional roles. Interest in this wellness-oriented application was consistently high among researchers and clinicians (68.2%), members of the general public (66.7%), and technology developers (50.0%).
- **Conclusion:** The **Diet/Fat Loss application demonstrates broad, cross-sector appeal**, suggesting it can serve as an effective **entry point for early market adoption**. The convergence of professional and consumer interest highlights the potential of metabolic self-monitoring as a unifying theme between research, healthcare, and lifestyle markets.

Table 22. Crosstabulation between Current Role and Use Case: Diet, with Chi-Square Test Results

		UseCase_Diet	
		Not Interested	Interested
CurrentRole_n	Researcher/Clinician	7 (31.8%)	15 (68.2%)
	Tech Developer/Engineer	2 (50.0%)	2 (50.0%)
	General Public / user	2 (33.3%)	4 (66.7%)
Total		11 (34.4%)	21 (65.6%)

(Note: Percentages by row. N=32 valid cases).

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.500a	2	.779

(a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is 1.38.)

Note: df = degrees of freedom; Asymp. Sig. (2-sided) = Asymptotic Significance (2-sided), which represents the p-value.

Summary Interpretation

Although exploratory in nature, these analyses consistently indicate that **accuracy, reliability, and ethical data management** are **universal user priorities**, independent of prior experience or professional background. This reinforces the need to position breath analysis technology as **scientifically credible, transparent, and trustworthy**, while maintaining a **simple and user-friendly interface**.

4.2.1.4 Predictive Model (Not Applicable)

Unlike the Personal Exposure survey, a multivariate predictive model (e.g., logistic regression) was not constructed for the Breath Analysis data. The small sample size (N=37) would not provide sufficient statistical power for such a model to yield reliable or meaningful results.

4.2.1.5 Summary of Quantitative Findings for Breath Analysis

The quantitative survey results for the Breath Analysis use case, while based on a small and specialized sample, provide clear directional insights:

- The target user is an **"Expert Novice"** demanding both scientific rigour and ease of use.
- The strongest market pull is towards **wellness applications (diet/metabolic tracking)** designed for self-monitoring.
- **Accuracy and Reliability** are the absolute, non-negotiable top priorities, followed closely by concerns about the **ethical handling of health data**.
- User preference shifts towards **professional guidance** when the application moves into the medical/diagnostic realm.
- Prior experience or self-assessed knowledge level does not significantly alter these fundamental priorities and concerns within this sample.



4.2.2 Results of the Co-Design Workshop

4.2.2.1 Overview and Key insights

A co-design workshop dedicated to the *Breath Analysis* use case gathered 8 participants to explore and validate potential scenarios, functionalities, and design attributes of the future breath analysis sensor. The session combined five interactive dynamics covering: (1) ideal context and use patterns, (2) prioritisation of user requirements, (3) physical design and interface features, (4) user journey mapping, and (5) engagement and scenario preference.

Synthesising the outcomes of all five dynamics provides a clear and actionable picture of user expectations, perceived barriers, and design opportunities for the AMUSENS breath analysis sensor. The findings point toward a user-driven roadmap that balances **scientific reliability**, **ethical trust**, and **emotional usability**.

At a glance

- Users prioritise **accuracy, simplicity, and interpreted results** over technical sophistication.
- **Trust and transparency** are decisive factors in adoption—data privacy is the most critical barrier.
- **Two differentiated device pathways** are envisioned: a compact personal sensor and a robust professional version.
- The **Stress & Fatigue** scenario stands out as the most relatable and viable entry point for market adoption.
- Institutional affiliation and professional guidance are key to building and sustaining user trust.

Key insights

1. **The ideal product ecosystem combines personal and professional use.**
Users clearly envision two complementary models:
 - A **personal device**, small, hygienic, and mobile-connected, tailored for individual wellness and self-assessment.
 - A **professional or clinical version**, larger and more durable, designed for use by healthcare professionals and researchers.
2. **Accuracy and trust are the foundation of adoption.**
Across all activities, *Accuracy* and *Reliability* emerged as the non-negotiable prerequisites for user acceptance. Participants equate measurement precision with ethical responsibility—errors or unclear results would directly erode confidence.
3. **Simplicity drives usability and engagement.**
The design should prioritise intuitive interaction and visual communication over technical density. Users prefer *interpreted outcomes* (e.g., traffic-light logic, graphs, simple scores) instead of raw data streams. Minimal on-device controls and a strong mobile interface are essential.
4. **Data transparency is a precondition for trust.**
The most significant adoption barrier is the lack of trust in how personal health data is managed. Users demand explicit, transparent communication about data storage, access, and use. Integration with public healthcare systems or regulated medical institutions is perceived as the strongest guarantee of safety.
5. **The Stress & Fatigue scenario presents the highest strategic potential.**
This scenario resonates across user profiles due to its broad relevance, emotional appeal, and potential contribution to mental health and wellbeing. It positions the breath sensor as a *preventive and empowering tool*, not just a diagnostic instrument. The *Respiratory Infections* scenario is a valuable secondary application for situational use, while *Ketosis* remains a niche case requiring professional oversight.

4.2.2.2 Dynamic 1: Ideal Sensor Design

This activity explored how users envision the *Breath Analysis* sensor functioning in everyday life across three potential application scenarios (*Ketosis / Diet & Metabolism*, *Stress & Fatigue*,

Respiratory Infections). Participants discussed where, how often, and in which format they would use the device, and how they would like to visualise the results.

At a glance

- Context of use varies by scenario but always favours comfort, convenience, and privacy.
- Frequency of use depends on professional supervision or situational triggers rather than continuous monitoring.
- Portable, mobile-connected formats dominate user preference; stationary models are consistently rejected.
- Visual, interpreted feedback (colours, graphs, actionable guidance) is essential to ensure understanding and trust.

Key findings

- **Context determines usability and trust.** Users consistently link professional supervision to credibility in medically oriented scenarios, while personal wellness contexts prioritise autonomy and convenience. Home, workplace, gym, and pharmacies emerge as preferred environments, depending on the use case.
- **Frequency of use is scenario-dependent.** Monitoring patterns diverge sharply: structured and professional-guided for metabolic tracking; on-demand for stress events; and symptom-triggered for infections. Across all cases, users reject constant self-monitoring due to perceived obsession or fatigue.
- **Portability and integration are non-negotiable.** Participants overwhelmingly favour a compact, mobile-connected device integrated into existing digital ecosystems such as smartphones or smartwatches. Fixed or stationary devices are considered impractical for real-world use.
- **Interpretation outweighs raw data.** Users do not want unprocessed measurements. Instead, they expect layered information: simple colour codes and scales for a quick overview, with optional graphs or numeric details for deeper insight.
- **Professional linkage reinforces trust.**

Across scenarios, participants request the possibility of sharing data with healthcare professionals or receiving expert recommendations directly through the app, bridging personal monitoring with medical oversight.

Design implications

- Design for contextual flexibility: align usability and data interpretation with the intended application scenario (wellness vs clinical).
- Prioritise mobile-connected, portable formats integrated with existing digital health ecosystems.
- Implement visual, multi-layered result displays combining simplicity (colour codes) with optional detail (trends, numbers).
- Enable secure, optional data sharing with professionals to enhance credibility and adoption.

Conclusion

Users envision the breath analysis sensor as a practical, mobile, and visually intuitive tool adaptable to diverse health and wellness contexts. Trust, clarity, and professional integration are decisive factors for adoption. The insights directly inform the sensor's hardware design and the app's data-visualisation strategy.

4.2.2.3 Dynamic 2: User Requirements

This activity focused on identifying and prioritising the essential features of the breath analysis sensor. Participants ranked nine predefined requirements and discussed missing dimensions. The goal was to capture what users consider indispensable for adopting and trusting the device.

At a glance

- **Accuracy and reliability** dominate all other requirements and are viewed as prerequisites for trust.



- **Ease of use** and **immediate feedback** are critical for everyday adoption, especially in wellness-oriented contexts.
- Users prefer **interpreted results** over real-time data streams.
- **Affordability** and **comfort** determine feasibility for personal use.
- Participants highlighted **cybersecurity**, **privacy**, and **interoperability** as missing but crucial elements.

Key findings

- **Accuracy is the foundation of trust.** Users unanimously identified accuracy and reliability as the top priority. Without confidence in the device's precision, all other features lose relevance. Trust in measurement quality is considered a non-negotiable prerequisite for use.
- **Simplicity drives engagement.** Ease of use ranked second, reflecting a strong desire for intuitive, straightforward operation. Users favour minimal steps, clear instructions, and automated data handling. Complexity or calibration difficulties are seen as barriers to long-term engagement.
- **Quick, interpretable results outweigh real-time monitoring.** Participants distinguished between *immediate feedback* and *real-time data*. They value fast, conclusive outcomes (“What does this mean for me now?”) over continuous streams of raw data, which they associate with confusion and anxiety.
- **Economic and ergonomic considerations matter.** Affordability and comfort emerged as secondary but decisive for sustained use. Devices that are too expensive, intrusive, or uncomfortable risk rejection—even if technically superior.
- **Missing dimensions: privacy and interoperability.** Several participants identified crucial omissions in the predefined list. They stressed the need for robust data protection, clear communication of privacy policies, and interoperability with healthcare systems or professional platforms. These are perceived as essential to long-term credibility and integration into users' routines.

Design implications

- Prioritise measurement accuracy and reliability in both hardware calibration and algorithmic interpretation.
- Simplify user interactions and minimise operational steps through automation and guided workflows.
- Replace continuous data streams with rapid, clearly interpreted results supported by visual indicators.
- Ensure affordability and physical comfort without compromising durability or performance.
- Integrate strong data governance principles—privacy, transparency, and interoperability—into the system architecture from the earliest design stages.

Conclusion

Accuracy, simplicity, and trust define the core expectations for the breath analysis sensor. Beyond technical reliability, users demand ethical assurance and transparency in how data are handled. These findings directly translate into actionable technical and design requirements that shape both product validation and user experience strategy.

4.2.2.4 Dynamic 3: Prototyping

This activity aimed to co-design the physical appearance and interaction model of the breath analysis sensor, including shape, size, colour, and interface icons. The exercise explored how aesthetic and ergonomic preferences intersect with usability, hygiene, and accessibility.

At a glance

- Users favour **compact, minimalist designs** with hygienic, durable materials.
- **Shape and size** must adapt to the context of use—small for personal devices, larger for professional or clinical models.
- **Neutral colours** are preferred, but **personalisation options** enhance emotional attachment and engagement.



- **Minimal on-device icons** are essential; users prefer to manage functions through a mobile app.
- **Physical buttons** for basic operations (e.g., power) improve accessibility and user confidence.

Key findings

- **Functional minimalism defines trust and usability.** Participants converged on a design philosophy centred on simplicity, hygiene, and durability. The preferred forms were *round* for wearable versions and *square or rectangular* for handheld models, provided they are easy to clean and resistant to damage.
- **Size must match context.** A compact, personal format is strongly preferred for everyday or wellness use. However, participants acknowledged that larger, more robust versions are appropriate for clinical or professional environments, where precision and resilience take precedence over portability.
- **Neutral aesthetics with optional personalisation.** While no dominant colour preference emerged, users generally favoured neutral tones (white, black, grey). The opportunity to customise colour or finish was seen as an added value that increases engagement and sense of ownership.
- **Minimalist interface, app-centric control.** Participants unanimously requested a reduction of on-device controls to the bare minimum. They prefer all complex functions to be managed through the mobile application, reserving the device surface for essential indicators only.
- **Physical accessibility improves confidence.** The inclusion of a physical button for powering on/off or triggering measurements was widely supported. This tangible element provides a sense of reliability and avoids accidental activation often associated with fully touch-based systems.

Design implications

- Adopt a minimalist, hygienic, and durable design using easily cleanable materials.
- Develop two scalable form factors—compact for personal use and robust for professional or clinical environments.
- Apply a neutral base aesthetic with optional personalisation to foster user identification.
- Prioritise app-based interaction; keep on-device controls limited to essential functions.
- Include at least one physical button to enhance accessibility, reliability, and user reassurance.

Conclusion

The ideal breath analysis sensor balances **aesthetic simplicity** with **functional robustness**. It must appear trustworthy, hygienic, and seamlessly integrated with its companion app. Users expect a product that feels personal yet professional, combining ergonomic design with emotional resonance to reinforce daily use and confidence in its readings.

4.2.2.5 Dynamic 4: User Journey Map

This activity mapped the complete user experience with the breath analysis sensor—from acquisition to daily use—identifying key emotions, motivations, barriers, and opportunities for behavioural change. The analysis revealed critical “make-or-break” moments that will determine long-term engagement and trust in both the device and the accompanying app.

At a glance

- **Curiosity and self-knowledge** drive initial **motivation** to acquire the device.
- **Privacy and data management** emerge as the greatest sources of **distrust**.
- **Ease of first use** and **clarity of guidance** are decisive for user **confidence**.
- **Interpreted, actionable results** are essential to maintain **engagement**.
- **Institutional trust** (e.g., affiliation with public healthcare) significantly increases **adoption potential**.

Key findings

- **Acquisition is driven by empowerment, tempered by caution.** At the purchase stage, participants are motivated by prevention and self-understanding (“knowing my health status



better”). However, this motivation is accompanied by anxiety about data misuse or self-misinterpretation of results. The device is perceived as an opportunity for self-care, provided it includes expert validation or contextual guidance.

- **Data entry triggers the strongest emotional resistance.** This stage represents the highest friction point in the journey. Users expressed deep mistrust regarding personal data handling and commercial exploitation (“they always sell personal data”). Transparency, institutional endorsement, and clear explanations of data governance are non-negotiable conditions for adoption.
- **First use defines long-term trust.** Initial interaction combines excitement and insecurity. Users fear operating errors or incorrect calibration may lead to unreliable readings. A smooth, guided onboarding process—using visual cues, step-by-step tutorials, and immediate feedback—is essential to build confidence.
- **Results consultation determines perceived value.** The moment of viewing results is both rewarding and anxiety-provoking. Users expect actionable insights (“what should I do now?”) rather than raw data. The absence of interpretation is seen as a barrier to continued use and may induce stress or confusion.
- **Trust hinges on human and institutional connection.** Participants clearly prefer systems associated with the public health sector or recognised medical institutions. Sharing data with trusted professionals enhances perceived legitimacy and willingness to continue using the device.

Design implications

- Frame device acquisition around empowerment and prevention, highlighting professional validation and societal value.
- Ensure transparent communication about data use, privacy, and ownership at the earliest interaction stage.
- Design an intuitive first-use experience with step-by-step visual guidance and immediate confirmation of proper operation.
- Present interpreted results supported by visual summaries and clear, actionable recommendations.
- Integrate secure data-sharing features with healthcare professionals to strengthen trust and perceived credibility.

Conclusion

The user journey underscores that **trust, transparency, and interpretation** are more influential than pure functionality. The emotional landscape—shaped by privacy concerns and the need for reassurance—must inform every design decision. Ensuring a guided, transparent, and professionally linked experience will be critical for fostering sustained engagement and long-term adoption.

4.2.2.6 Dynamic 5: Engagement and Scenario Selection

This final activity assessed users’ willingness to engage with the breath analysis ecosystem and identified the most compelling use-case scenario for early market adoption. The session combined two exercises: (1) rating comfort levels with key user actions, and (2) selecting and justifying their preferred application scenario among *Ketosis (Diet & Metabolism)*, *Stress & Fatigue*, and *Respiratory Infections*.

At a glance

- Users are **highly receptive to app-based and professional-linked interaction**.
- **Data privacy** remains the single largest barrier to adoption.
- **Trust in institutional or medical affiliation** is essential for user confidence.
- The **Stress & Fatigue** scenario received the strongest preference due to its broad personal relevance.
- Users advocate for **transparent data management and professional feedback loops** as preconditions for engagement.

Key findings

- **Digital and professional engagement are welcomed.** Participants expressed strong comfort with using a dedicated mobile application and sharing data with healthcare professionals. These interactions are perceived as beneficial, improving health monitoring and enabling more informed consultations.
- **Calibration is accepted as a necessary step.** Users regard calibration as an acceptable task that ensures data reliability. They see it as an investment in accuracy rather than an inconvenience, provided that the process is simple and guided.
- **Data privacy remains the greatest obstacle.** Providing personal data elicited strong negative reactions. The sentiment of distrust towards private companies (“privacy should not be a market value”) reveals a critical barrier to adoption. Users require explicit information on who accesses their data, for what purpose, and under which security guarantees.
- **Trust is conditional on affiliation and transparency.** Participants’ willingness to share data is directly linked to institutional trust. Devices associated with public healthcare systems or regulated medical entities are perceived as credible and safe. Trust in private, commercial platforms remains extremely low.
- **Scenario preference highlights stress monitoring as the most relevant use case.** Voting results placed **Stress & Fatigue** as the preferred scenario, followed by **Respiratory Infections**, with **Ketosis** ranking last.
 - *Stress & Fatigue* was viewed as the most relatable and beneficial for daily wellbeing (“It helps me understand and reduce daily stress”).
 - *Respiratory Infections* attracted interest for its strong diagnostic potential and preventive function (“Useful when you have symptoms, for fast confirmation”).
 - *Ketosis* was considered niche, medically sensitive, and potentially unsafe without professional supervision (“This should not be used without a doctor”).

Design implications

- Embed robust privacy and data protection mechanisms, communicated transparently and in user-friendly language.
- Leverage mobile connectivity as the central interaction hub, with secure channels for data sharing with trusted healthcare professionals.
- Frame calibration as part of the accuracy assurance process, integrating clear guidance and feedback to reinforce trust.
- Prioritise early development around the *Stress & Fatigue* scenario, framed within the wider mental health and wellbeing context for broader societal impact.
- Explore regulatory and institutional partnerships (e.g., healthcare or public research bodies) to reinforce credibility and support market adoption.

Conclusion

User engagement is defined by **trust, transparency, and perceived personal benefit**. The strong preference for the *Stress & Fatigue* scenario underscores the importance of positioning the sensor within the mental health and wellbeing ecosystem rather than a purely medical or diagnostic framework. Clear data governance, professional integration, and emotional relevance are the critical levers for sustained participation and large-scale adoption.

4.2.2.7 Summary

The co-design outcomes demonstrate that the success of the AMUSENS breath analysis sensor depends not only on its **technical excellence** but on its ability to **earn user trust** and **foster responsible engagement**. By aligning design choices with ethical standards, societal priorities, and professional frameworks, the project ensures that innovation remains both *technologically sound* and *socially meaningful*. This user-centred vision provides a strong foundation for the transition from concept validation (WP6) to sensor testing and exploitation (WP8 and WP10).

4.3 European validation Workshop

4.3.1 Results of the Co-Design Workshop

This pan-European session consolidated and stress-tested insights from the national workshops, with two parallel groups working on **Personal Exposure (PE)** and **Breath Analysis (BA)**. The workshop pursued a dual objective: (i) **validate** and **refine** previously identified needs, and (ii) surface **convergences** (shared requirements for a unified platform) and **divergences** (domain-specific needs that require distinct pathways) to inform the technical development WPs.

4.3.1.1 Dynamic 1: User Requirements

This dynamic examined foundational user expectations across form factor preferences, requirement prioritisation, and trust drivers for both Personal Exposure (PE) and Breath Analysis (BA) scenarios. Participants consistently favoured compact, discreet, and app-centric portable devices, with fixed units positioned as context-specific complements. Accuracy, ease of use, and data protection emerged as universal priorities, while scenario-specific trade-offs surfaced: PE users emphasised comfort and battery autonomy for everyday wear, whereas BA users accepted lower comfort and autonomy if accuracy and immediacy were maximised. Trust was shown to depend on demonstrable validation, transparency, and user control, with BA participants demanding stringent privacy safeguards and zero data monetisation. Overall, the results confirm the need for a unified, privacy-first, clinically credible architecture with modular physical and functional adaptations per use-case context.

Exercise 1: Brainstorming the ideal form factor (Portable vs. Fixed)

At a glance

- **Convergence:** miniaturisation, discretion, low energy, durability, app-centric UX.
- **Divergence:**
 - **PE** emphasises ornamental home blending and multi-channel alerts.
 - **BA** elevates hygiene and contactless interaction; fixed/public stations are acceptable in shared contexts.

Key findings

- **PE** Portable: small/thin/light; wearable (watch/bracelet/necklace/brooch); shock-proof; ≥1-day battery; easy to find (keychain); affordable, reliable.
- **PE** Fixed: small footprint; low energy; multiple notifications (sound/light/app); “ornamental” design; simple connectivity (including offline); may sync with a portable node.
- **BA** Portable: very compact; wearable; hygiene-first (easy-clean, contactless short-distance blow); minimalist (1–2 buttons); waterproof; universal charging; no on-device screen if app is primary; one-tap “measure.”
- **BA** Fixed: viable for public/shared spaces (gym/school/clinic); always-powered; multi-protocol comms; easy to clean/move.

Design implications

- Prioritise compact, discreet, wearable portable devices for both use cases; offer fixed nodes where context demands.
- For BA, mandate contactless intake options and easy sanitation; for PE, ensure multi-channel alerting on device + app.
- Standardise an app-first UI to simplify hardware and unify experiences.

Conclusion

Participants demonstrated strong alignment around portability, durability, and discretion as essential attributes for both systems, while diverging on the role of hygiene and alerting mechanisms. The design must therefore balance a unified app-based core with use-case-specific physical features—ornamental and multi-modal for PE, sanitary and contactless for BA.

Exercise 2: Prioritising Requirements

At a glance

- **Shared baseline:** Accuracy/Reliability and Ease of Use remain non-negotiable.
- **Trade-offs differ:**
 - **PE** demands a balanced quartet (Ease, Comfort, Accuracy, Autonomy).
 - **BA** accepts lower Comfort/Autonomy if Accuracy + Immediacy are maximised.

Ranked results

- **PE** — Tier 1 (6 votes each): Ease of Use; Comfort; Accuracy & Reliability; Autonomy. Tier 2 (4 votes): Connectivity; Affordability. Low priority (≤ 1): Real-time feedback; On-device indicators; Immediate feedback.
- **BA** — Top to bottom: Accuracy & Reliability (7) → Immediate feedback (6) → Real-time feedback (5) → Affordability (4) → Connectivity (4) → Ease of Use (4) → Comfort (3) → Autonomy (3) → On device indicators (3).

Design implications

- **PE:** Optimise battery life and comfort without compromising accuracy.
- **BA:** Deliver fast, interpreted results with medical-grade accuracy; Comfort/Autonomy are secondary.
- Maintain affordability and baseline connectivity across both.

Conclusion

The prioritisation exercise confirmed that accuracy and reliability dominate user expectations, while secondary priorities diverge by context. PE users demand comfort and autonomy for daily usability, whereas BA users accept trade-offs if accuracy and immediacy are ensured. This differentiation provides clear guidance for technical specifications in WP7 and usability calibration in WP8.

Exercise 3: Trust & Distrust Factors

At a glance

- **Trust pillars** shared: Validation + Transparency + Quality UX.
- **Red lines** differ:
 - **BA:** zero tolerance for data monetisation/ads; strict clinical-grade privacy.
 - **PE:** tolerance higher if certification, reliability and alerting are evident.

Key findings

- **Builds trust (PE):** EU/authority certification; explicit purpose & error margins; calibration options; user data control; self-diagnostics; brand reputation; authentic reviews.
- **Builds trust (BA):** verifiable accuracy/reproducibility; tangible health benefit; simple UX to minimise user error; minimal data intrusion; clear, non-subscription business model.
- **Erodes trust (PE):** inconsistent readings; fragile/buggy hardware; alert fatigue; weak institutional backing.
- **Erodes trust (BA):** inaccuracy; data sold/shared with insurers/third parties; opaque tech; ads/pushy monetisation; no tangible benefit.

Design implications

- Publish validation evidence (methods, reference comparisons, certification).
- Enforce privacy-by-design, plain-language data-use summaries, and no advertising in health contexts.
- Implement self-diagnostics and visible calibration status to sustain trust.

Conclusion

Trust emerged as a decisive adoption factor, deeply tied to verification, transparency, and control. Participants reinforced that **trust must be demonstrable, not assumed**, requiring tangible proof of accuracy, privacy guarantees, and system integrity. The AMUSENS platform must thus embed these trust mechanisms into every layer of its design—from data governance to user interface.



4.3.1.2 Dynamic 2: Empathy & User Journey

This dynamic mapped the full user experience across both use cases, from initial acquisition to long-term use and interpretation. Participants revealed two recurring friction points: the **complexity of calibration/setup** and the **lack of guidance after receiving an alert or measurement**. For PE, the challenge lies in transforming alerts into concrete actions, while for BA, it lies in translating data into meaningful, professionally validated insights. Across both, users demand a smooth onboarding process, transparent calibration feedback, and sustained confidence through clarity, guidance, and contextual support.

At a glance

- **Two critical frictions recur:** (1) Calibration/setup complexity; (2) Post-alert/interpretation gap.
- **Pathways differ:**
 - **PE:** must close the alert → action gap with contextual guidance.
 - **BA:** must close the data → interpretation gap via professional pathways.

Personal Exposure — stages & needs

- **Getting the sensor:** curiosity vs. cost/utility; needs quick start and examples.
- **Calibration & first data:** major friction; needs guided setup, references, auto-checks.
- **Daily monitoring:** positive if trends are clear; barriers: battery/size/forgetting/reliability doubt.
- **Risk detection:** anxiety if no actionable steps; needs graded alerts, indoor/outdoor context.
- **Decision-making:** requires simple, actionable advice; success = behaviour change (ventilate, avoid route, filters).

Breath Analysis — stages & needs

- **Getting the sensor:** health-driven; cost/compatibility concerns; early clinician comparison valued.
- **Calibration:** “necessary evil”; target one-tap/AI-assisted with success confirmation.
- **Personal data:** biggest trust hurdle; share minimally with granular control; prefer professional pathway.
- **Health measurements:** fast, simple, repeatable; avoid measurement fatigue; trend tracking.
- **Consult results (App):** without interpretation → confusion/anxiety; needs clear explanations, next steps, and clinician link; visuals help but are insufficient alone.

Design implications

- Auto-calibration, reference checks, and success confirmations.
- **PE:** Contextual, proportional alerts + recommended actions (e.g., “Open window; reduce heat”).
- **BA:** Embedded professional channel for interpretation and advice.

Conclusion

This dynamic clarified the critical points of user friction along the experience curve, identifying where each system must provide stronger support. PE requires actionable alerts and simple behaviour prompts, while BA demands data interpretation and professional connectivity. Both converge in the need for guided onboarding and sustained user confidence through clarity and control.

4.3.1.3 Dynamic 3: Validation of Previous Results

This dynamic served to validate and stress-test the insights gathered in earlier sessions. Participants broadly confirmed core principles—**universal accessibility**, **layered information**, and **actionable guidance**—while refining the boundaries of system autonomy and user control. Key points of contention emerged regarding visual conventions (e.g., traffic-light indicators), interface hierarchy, and the acceptable degree of automation and institutional data linkage. The exercise ultimately reinforced a design posture based on **flexibility**, **configurability**, and **user agency**, rather than rigid defaults or prescriptive automation.

Validated across groups

- **Universal accessibility** (easy to use/understand/afford).
- **Layered information model:** simple first layer with optional deeper real-time/history.



- **Actionable guidance:** users want recommendations, not only numbers.

Contested points

- **Traffic-light as primary:** useful for some; many neutral → keep optional, not prescriptive.
- **Mobile app as primary interface:** central, but desktop companion is valued for deep dives.
- **“Active partner” automating emergency actions:** rejected; users want agency.
- **BA ↔ public health interoperability:** divisive (privacy/discrimination concerns; cross-border feasibility).

Design implications

- Optional traffic-light; configurable dashboards by user profile.
- Provide desktop web for advanced analysis/export.
- Treat institutional data links as opt-in with explicit, granular consent and local compliance controls.

Conclusion

Participants largely validated earlier findings, confirming the value of layered, user-controlled interfaces. They rejected automation that limits autonomy and warned against overly prescriptive visual conventions. The conclusion reinforces a design ethos centred on flexibility, user agency, and contextual interoperability rather than universal uniformity.

4.3.1.4 Dynamic 4: Comparison and Consolidation of Use Cases

This dynamic focused on aligning the Personal Exposure and Breath Analysis use cases to identify shared foundations and context-specific divergences. Participants confirmed strong convergence around **accuracy, ease of use, affordability, and interpretable feedback**, forming a unified platform baseline. However, clear divergence emerged in **data sensitivity, target contexts, and behavioural pathways**, requiring differentiated ethical and technical approaches. The consolidation exercise validated a **modular, dual-pathway architecture**: shared core technology and interaction logic, complemented by separate privacy, alerting, and action-guidance models for environmental versus health-driven applications.

Convergences (platform level)

- **Accuracy/Reliability** as foundation.
- **Ease of use and Affordability** to enable adoption.
- **Immediate, interpretable feedback;** consistent, intuitive presentation across devices.

Divergences (pathway level)

- **Data sensitivity:**
 - **PE:** aggregate/geo-linked data can be shareable if de-identified.
 - **BA:** health data private by default; share only under user-controlled, clinician-oriented flows.

Target & context:

- **PE:** general-public/environmental; acceptable in public if discreet; fixed nodes sometimes preferred on-site.
- **BA:** personal/health; predominantly private/home use; long-term adherence likely only if smartphone-integrated.

Action paradigm:

- **PE:** external mitigation (ventilation, avoidance, filters).
- **BA:** internal habit/clinical actions (diet, hygiene, check-ups) contingent on professional validation.

Design implications

- Two data governance tiers: environmental (PE) vs. health (BA), with stricter controls for the latter.
- Shared core platform with use-case-specific modules (alerting vs. interpretation/pro referral).

Conclusion

The consolidation exercise demonstrated that **technological convergence is feasible**, provided

that **ethical and contextual divergences are formally embedded in design architecture**. The project must thus sustain a shared technological foundation while preserving differentiated pathways for environmental and health data governance.

4.3.1.5 Dynamic 5: Final Discussion and Key Takeaways

This final discussion synthesised insights across all co-design exercises, confirming a shared foundation—**accuracy, reliability, and ease of use as primary adoption drivers**—while emphasising distinct contextual needs for each use case. Personal Exposure demands **wearability, discretion, and situational awareness for daily use**, whereas Breath Analysis requires **trusted calibration, strict data safeguards, and clinically interpretable outputs**. Behaviourally, Personal Exposure prompts **immediate environmental mitigation**, while Breath Analysis supports **progressive lifestyle adjustments guided by professional input**. These insights reinforce the dual-pathway development strategy, balancing a **common platform core** with **specialised workflows**, privacy models, and interaction paradigms for environmental and health applications.

Objective: To consolidate overarching lessons on technical priorities, contextual use, and behavioural implications across both use cases.

- **Technical priorities**
 - **Both:** Accuracy/reliability first; ease of use next.
 - **PE:** Wearability and convenience for everyday contexts; data access for awareness.
 - **BA:** Standardised **calibration, data protection**, swift **interpreted** results; trust for sharing with clinicians.
- **Implementation contexts**
 - **PE:** Acceptable in public if discreet; sometimes prefer using **existing fixed sensors** on-site.
 - **BA:** Prefer **private/home** settings; public use seen as awkward; long-term adherence likely only if **integrated into the smartphone** ecosystem.
- **Behavioural impact**
 - **PE:** Avoid/mitigate exposure; ventilation; filter use; environment-linked routine changes; connect exposure with symptoms.
 - **BA:** Adjust lifestyle (diet, hygiene, training), **inform clinician**, gradual change with guidance; professional validation is a precondition for major actions.

Conclusion

This discussion reaffirmed accuracy, reliability, and ease of use as shared foundations, while highlighting distinct adoption needs: **everyday discretion and actionable cues for PE**, and **clinical validation and interpreted guidance for BA**. The group endorsed a shared core system with differentiated pathways, ensuring relevance across daily exposure contexts and health-related monitoring.

4.4 Executive summaries (by use case)

4.4.1 Personal Exposure

The success of the **Personal Exposure (PE)** sensor depends on a **non-negotiable quartet** of attributes: **accuracy, ease of use, comfort/wearability, and battery autonomy**.

The co-design findings reveal two critical friction points in the user journey: (i) **calibration**, which must be simplified and automated, and (ii) the **alert-to-action gap**, which must be bridged through contextual, proportional, and actionable guidance.

Participants consistently rejected any form of automation that substitutes user agency. They seek **clear information, not automatic decision-making**, valuing transparency and control above passive convenience.

Building and sustaining trust requires **formal certification, transparent error margins, and calibrated, non-intrusive alerting mechanisms** that prevent notification fatigue.



Ultimately, the PE sensor must function as a **trusted personal companion**—intelligent, responsive, and interpretable—supporting immediate protective actions while maintaining the user’s full control and confidence.

4.4.2 **Breath Analysis**

The **Breath Analysis (BA)** sensor is perceived as a **health instrument, not a consumer gadget**. Its value hierarchy is explicit: medical-grade accuracy, followed by immediacy of interpreted results, and strict data privacy.

Users are willing to share results with clinicians under secure, user-controlled conditions, but they are strongly opposed to any commercial or opaque data use. This implies granular consent mechanisms, no advertising, and explicit guarantees against data sale or reuse.

Ease of use and hygiene are crucial for sustained adoption. The device should be contactless, discreet, and quick to operate, with minimal calibration requirements. Integration with the mobile phone is essential to avoid novelty decay and to ensure continuous engagement.

Finally, the app interface must go beyond measurement by translating data into actionable health insights, offering guided interpretation and professional referral pathways when relevant.

Chapter 5 Consolidated User Requirements

This chapter synthesises the qualitative and quantitative findings from the three co-design workshops and the pan-European survey conducted within Task 6.5. It presents a prioritised and actionable framework to guide the **technical development of the AMUSENS single and multi-pixel sensors**, as well as their **digital ecosystem**.

The synthesis integrates insights from both **Personal Exposure (PE)** and **Breath Analysis (BA)** use cases, identifying shared priorities, differentiated needs, and cross-cutting design principles that inform sensor design, data management, and interface development.

Table 23. Prioritised hierarchy of consolidated user requirements (PE and BA combined)

Priority Level	Requirement	Description
1	Accuracy and Reliability	Users demand scientifically validated, reproducible data. Tolerance for error is extremely low, particularly in the BA context. Calibration indicators and third-party certification are essential to maintain confidence.
2	Ease of Use	The device must be intuitive and require minimal setup. Interfaces should guide the user step-by-step, ensuring accessibility for all demographics. Technical complexity must remain invisible to the end-user.
3	Data Privacy and Security	A non-negotiable requirement across both use cases. Users require full transparency on data storage, use, and sharing. Privacy-by-design, explicit consent flows, and local data processing (when feasible) must be standard.
4	Immediate, Interpreted Feedback	Users do not seek raw data but clear, actionable insights. Feedback must be visual, proportional, and accompanied by concise guidance (e.g., “Open a window,” “Consult a physician”).
5	Comfort and Portability	Critical for the PE sensor, which must be lightweight, discreet, and ergonomic. Integration into wearables or everyday objects (e.g., pendant, keychain, wristband) enhances adoption.
6	Connectivity and Integration	The mobile application must act as the central hub, consolidating measurement, interpretation, and history. Compatibility with broader environmental and health-monitoring systems should be planned.
7	Affordability	Accessibility of price is directly tied to adoption. The perceived benefit-to-cost ratio must be clear, especially for non-clinical applications.
8	Battery Autonomy	Extended battery life is vital to prevent fatigue and ensure continuous operation. Minimum target: several days for portable units and 24/7 uptime for fixed stations.
9	Hygiene and Durability	Especially for BA, hygiene is critical. Materials should enable contactless or easy-clean use. Both devices must be resistant to shocks, humidity, and routine wear.

To complement the prioritised list above, the following summary provides a **comparative overview of converging and diverging requirements** across the two AMUSENS use cases. While both the Personal Exposure (PE) and Breath Analysis (BA) scenarios share a foundation of accuracy, sim-

plicity, and trust, their **contexts of use, adoption drivers, and ethical considerations** differ substantially. The table below synthesises these contrasts, clarifying which requirements are **platform-level constants** and which require **use case-specific design strategies**.

Table 24. Comparative Overview of Converging and Diverging Requirements Across Use Cases (Personal Exposure and Breath Analysis)

Dimension	Shared Requirements (Both Use Cases)	Personal Exposure (PE) – Specific Focus	Breath Analysis (BA) – Specific Focus
Core Value	Accuracy, reliability, and trust are essential for adoption.	Preventive environmental awareness and user empowerment.	Health monitoring and professional validation.
Primary Context of Use	Daily life and self-monitoring environments.	Outdoor/indoor exposure, mobility contexts.	Indoor, private or semi-clinical settings.
Top Priority	Scientifically validated data and clear interpretation.	Portability, comfort, and autonomy (wearable design).	Medical-grade precision and hygiene.
Interface Expectations	Immediate, visual feedback with actionable meaning.	Multi-modal alerts (sound, vibration, mobile).	Interpreted health feedback, calm tone, no alarmism.
Privacy & Data Handling	Full transparency and control; no commercial data use.	Local environmental data, optional sharing within household/community.	Health data managed under strict consent; clinician-only sharing.
Calibration & Maintenance	Must be simplified, visible, and trustworthy.	Auto-calibration preferred; minimal user input.	One-tap or AI-assisted calibration for clinical credibility.
Adoption Barriers	Complexity, unclear value, and low data trust.	Technical maintenance, battery fatigue.	Privacy concerns, fear of misinterpretation.
Motivational Triggers	Empowerment through knowledge and prevention.	Reducing exposure, improving safety and air quality.	Monitoring health status, stress, and fatigue management.
Product Ecosystem	Both rely on mobile app as central interaction hub.	Wearable sensor + fixed hub compatibility.	Portable personal device + clinical/public stations.
Key Success Factor	Transparent, actionable, and reliable experience.	Contextual alerts and perceived control.	Medical legitimacy and privacy assurance.

5.1 Core Design Principles

Drawing from the prioritised requirements and validated workshop insights, five cross-cutting design principles are defined to guide the development of AMUSENS hardware, firmware, and software components.

5.1.1 *Simplicity and Guidance by Design*

- Interfaces must reduce cognitive load and present information progressively: an intuitive first layer with optional deeper insights.



- Onboarding and calibration should be **guided, automated, and contextual**, minimising user effort.
- Provide **step-by-step assistance** and in-situ guidance (e.g., during setup, calibration, or alert response).

5.1.2 Transparency and Trustworthiness

- Communicate **error margins, data handling policies, and sensor calibration status** in accessible language.
- Use **visible cues** (e.g., “data stored locally,” “calibration valid”) to reinforce confidence.
- Maintain full compliance with **GDPR** and anticipate the **EU AI Act** principles on transparency and accountability.

5.1.3 Actionability and Behavioural Relevance

- Translate complex data into **practical, proportional, and actionable guidance**.
- Include **adaptive recommendations** informed by user patterns and environmental context.
- Alerts should **inform, not alarm**, maintaining proportionality and avoiding “alert fatigue.”

5.1.4 Personalisation and Context Awareness

- Allow user control over **frequency, notification type, and visual style**.
- Adapt dynamically to context of use: **private vs. public, environmental vs. health-related**.
- Support optional, **user-controlled integration** with professional or clinical services.
- Develop a **modular architecture** allowing the same hardware and app ecosystem to serve both use cases through configurable modules.
- Enable secure interoperability with **external systems** (e.g., environmental databases, electronic health records) while maintaining **strict data segregation** between use cases.

5.2 Actionable Recommendations for Technical Work Packages

To operationalise the consolidated findings, the following recommendations translate user requirements into **technical priorities** for the corresponding Work Packages.

5.2.1 For Sensor Hardware

- Develop a **dual-format design**:
 - **Wearable/portable node** for Personal Exposure.
 - **Contactless desktop or mobile interface** for Breath Analysis.
- Integrate **automatic calibration** and **on-device indicators** for sensor health and error reporting.
- Apply **hypoallergenic and easy-clean materials**; meet IP standards for water and dust resistance.
- Prioritise **low energy consumption** with a minimum autonomy under standard conditions.

5.2.2 For Mobile Application and Dashboard

- Centralise all user interaction in the **mobile application**, including data collection, visualisation, and interpretation.
- Deliver **interpreted feedback** through layered data displays, with contextual recommendations.
- Integrate **trust indicators** (e.g., “Measurement verified,” “Data encrypted locally”).
- Ensure **multilingual support** and **WCAG 2.2 accessibility compliance** for inclusivity across age and ability groups.

5.2.3 For Data Management and Privacy

- Implement **local-first processing** with explicit consent for any cloud synchronisation.



- Segregate databases for **environmental (PE)** and **medical (BA)** data.
- Apply **pseudonymisation** and **end-to-end encryption** across all data flows.
- Provide transparent **user dashboards** for consent management, data access, deletion, and export.

5.2.4 For Validation and Pilots

- Conduct **mixed-method evaluation** (quantitative and qualitative) under real-life conditions.
- Measure **trust, usability, and sustained engagement** as key success indicators.
- Include **healthcare professionals** in BA pilots to verify result interpretability and reliability.
- Integrate findings from pilot testing back into the sensor and app iteration cycle.

5.3 Strategic Implications

The convergence of results across workshops and surveys confirms a shared foundation of **accuracy, trust, and simplicity**, yet reveals distinct contextual applications:

- **Personal Exposure (PE)** operates within an **environmental awareness paradigm**, emphasising preventive and behavioural change (ventilation, avoidance, filtration).
- **Breath Analysis (BA)** functions within a **healthcare paradigm**, demanding clinical reliability, data confidentiality, and professional validation pathways.

Accordingly, AMUSENS should adopt a **modular dual-product strategy**, where both devices share a **common architecture, ethical standards, and data model**, while offering **differentiated front-end experiences and governance frameworks**.

This strategic design ensures efficiency in technical development while meeting the psychological, ethical, and practical expectations of each user segment. By doing so, AMUSENS positions itself as a **user-validated, ethically aligned, and societally relevant innovation**, bridging environmental and health domains under one coherent technological and methodological framework.



Chapter 6 Summary and Conclusion

This deliverable has established the foundational user-centred requirements for the AMUSENS single-sensor platform. By combining survey data with co-design and participatory workshops, Task 6.5 has systematically explored expectations, perceived value, concerns, and usage contexts associated with Personal Exposure and Breath Analysis applications. This dual focus enables the project to address both environmental monitoring and health-related sensing within a unified innovation framework.

The findings demonstrate that while application contexts differ, user priorities converge on several core principles: high-accuracy sensing, ease of use, data privacy and transparency, and actionable interpretation of results. Users expect simple and intuitive interfaces, minimal calibration burden, and rapid, meaningful feedback. Importantly, participants express a strong preference for **interpreted insights over raw data**, emphasising clarity, trust, and usability as critical drivers of adoption. Distinct expectations also emerge: Personal Exposure users prioritise wearability, comfort, and continuous monitoring, whereas Breath Analysis users emphasise hygiene, clinical-grade reliability, and trusted professional integration.

The deliverable translates these insights into a prioritised list of user requirements, cross-cutting design principles, and technical recommendations for subsequent WPs. These elements will directly inform sensor engineering, data architecture, user-interface design, and pilot-validation activities. In this way, WP6 ensures that technological innovation within AMUSENS remains guided by user trust, societal needs, and ethical standards.

In conclusion, the results presented here validate the relevance and strategic importance of a human-centred design approach for AMUSENS. They provide a solid foundation for technical development and risk-mitigation, supporting both performance objectives and user-acceptance pathways. Going forward, the priorities and requirements articulated in this deliverable will serve as a reference framework for multidisciplinary decision-making across WP4–WP8, ensuring alignment between technological ambition, societal values, and real-world deployment conditions.

6.1.1 Addressing Stakeholder Limitations and Future Roadmap

The co-design activities presented in this deliverable have successfully defined the user-centric requirements for the AMUSENS platform, with strong engagement from end-users. However, the consortium identifies a limitation in the current phase regarding the direct involvement of researchers, industrial and regulatory actors in the early design workshops. As highlighted in the Stakeholder Mapping (Section 3.4), these actors are critical for the uptake and standardization of the technology.

Therefore, the roadmap for the next period explicitly includes the activation of the stakeholders identified in Annex 1. Stakeholder Mapping – Personal Exposure and



Annex 2. Stakeholder Mapping – Breath Analysis. Future activities will engage these stakeholders to refine the technical specifications defined in this document (Chapter 5), ensuring the final product is not only desirable for users but also viable for the market and compliant with EU standards.

Chapter 7 List of Abbreviations

Abbreviation	Translation
AI	Artificial Intelligence
AMUSENS	Adaptable multi-pixel gas sensor platform for a wide range of appliance and consumer markets
BA	Breath Analysis
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
COVID	Coronavirus Disease
COVID-19	Coronavirus Disease 2019
D6.3	Deliverable 6.3
DPO	Data Protection Officer
EU	European Union
GDPR	General Data Protection Regulation
IAQ	Indoor Air Quality
LIST	Luxembourg Institute of Science and Technology
NO	Nitric Oxide
PE	Personal Exposure
PM	Particulate Matter
ppm	Parts-per-million
ppt	Parts-per-trillion
RRI	Responsible Research and Innovation
SFC	Science For Change
SSH	Social Sciences and Humanities
UCD	User-Centred Design
UI	User Interface
UX	User Experience
VOC	Volatile Organic Compound
WP	Work Package



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Chapter 9 Annexes

9.1 Annex 1. Stakeholder Mapping – Personal Exposure

The following tables present the organisations identified during the stakeholder mapping process specifically for the **Personal Exposure** use case. Personal contact details have been removed for data protection.

Table 25. Academic & Research stakeholders identified for Personal Exposure

Organization	Country
Atmospheric Data Synergies, Atmospheric Reactive Gases, Royal Belgian Institute for Space Aeronomy (BIRA-IASB)	Belgium
Institute of Physics, University of Tartu	Estonia
NanoMIR, Institute of Electronics and Systems (IES), University of Montpellier	France
MINAMAS (Micro-Nano Materials and Surfaces), FEMTO-ST Institute	France
Interdisciplinary Carnot de Bourgogne Laboratory, University of Burgundy–Franche-Comté	France
Chrono-Environment Laboratory, University of Burgundy–Franche-Comté	France
Jean Lamour Institute – Bio-Sourced Materials Group	France
Institute of Electronics, Microelectronics and Nanotechnology (IEMN), University of Lille	France
Institute of Analytical Sciences and Physico-Chemistry for Environment and Materials (IPREM), University of Pau and Pays de l'Adour (UPPA)	France
Department of Atmospheric Sciences and Environmental Engineering (SAGE), IMT Lille Douai	France
Physico-Chemistry of Combustion and Atmospheric Processes Laboratory (PC2A), University of Lille	France
MINATEC Campus, University Grenoble Alpes	France
Vibro-Acoustics and Sound Systems Group (ViBS), GIPSA-Lab, University Grenoble Alpes	France
Optimisation of Physiological Responses (ORPHY), Faculty of Science and Technology, University of Western Brittany (UBO)	France
ICube Laboratory, University of Strasbourg and CNRS	France
Institut Polytechnique de Paris (IPP)	France
Department of Electronics and Physics, Télécom SudParis	France



ARMEDIA – Applied Research for Multimedia Enrichment, Diffusion, Interaction and Analysis, SAMOVAR Laboratory	France
Instrumentation, Modelling, Simulation and Experimentation (IMSE), COSYS Department	France
Mixed-Valence Oxides Group (OVM), CIRIMAT (Inter-University Center for Materials Research and Engineering)	France
Health and Environment Group, Laboratory for Analysis and Architecture of Systems (LAAS-CNRS)	France
Institute of Research on Catalysis and Environment of Lyon (IRCELYON)	France
IMT Mines Alès	France
Climate and Environment Sciences Laboratory (LSCE-IPSL), CNRS–CEA–UVSQ	France
Climate and Environment Sciences Laboratory (LSCE-IPSL), IPSL/CEA/CNRS/UVSQ	France
DAVID Laboratory, University of Versailles Saint-Quentin-en-Yvelines (UVSQ)	France
EPAR Team, Faculty of Medicine Saint-Antoine, INSERM & Sorbonne University	France
HP2 Laboratory, University Grenoble Alpes	France
Computer Science Laboratory (LIP6), Sorbonne University	France
CEA-LETI (Laboratory for Electronics and Information Technology), University Grenoble Alpes	France
CEA-LITEN (Laboratory for Innovation in New Energy Technologies), University Grenoble Alpes	France
Grenoble Institute of Nanophysics (GINP), Grenoble INP – Minatec	France
Laboratory for Emerging Nanometrology (LENA), Institute of Semiconductor Technology (IHT), Technische Universität Braunschweig	Germany
Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology Cottbus–Senftenberg (BTU)	Germany
Department of Cardiology I, University Medical Center Mainz, Johannes Gutenberg University Mainz	Germany
German Centre for Cardiovascular Research (DZHK)	Germany
Laboratory for Modelling and Observation of the Earth System (LAMOS), Institute of Environmental Physics, University of Bremen	Germany
Remote Sensing Technology Group, School of Engineering and Design, Technical University of Munich (TUM)	Germany
German Aerospace Center (DLR), Remote Sensing Technology Institute	Germany
Department of Internal Medicine V – Pulmonology, Allergology and Respiratory Critical Care Medicine, Saarland University	Germany



Division of Lung Immunology, Priority Area Asthma and Allergy, Research Center Borstel – Leibniz Lung Center	Germany
Regional Climate Change and Health Group, Faculty of Medicine, University of Augsburg	Germany
Human Geography and Transition Research Group, University of Augsburg	Germany
E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate, RWTH Aachen University	Germany
Department of Flue Gas Cleaning and Air Quality Control, University of Stuttgart	Germany
Institute of Physiology, Charité – Universitätsmedizin Berlin (corporate member of Freie Universität Berlin and Humboldt University of Berlin)	Germany
CBS International Business School	Germany
Department of Effect-Directed Analysis, Helmholtz Centre for Environmental Research (UFZ)	Germany
Department of Urban and Environmental Sociology, Helmholtz Centre for Environmental Research (UFZ)	Germany
Department of Social Psychology, Institute of Psychology, Leipzig University	Germany
Centre for Environmental Biotechnology, Helmholtz Centre for Environmental Research (UFZ), Leipzig	Germany
German Aerospace Center (DLR), Mobility and Urban Development	Germany
Institute of Combustion and Power Plant Technology, University of Stuttgart	Germany
Physical Geography and Climate Science Group, University of Augsburg	Germany
Research Institute for Sustainability (RIFS), GFZ Potsdam	Germany
Geography Department, Humboldt University of Berlin	Germany
Environmental Engineering Laboratory, Department of Chemical Engineering, Aristotle University of Thessaloniki (AUTH)	Greece
Atmospheric Chemistry and Innovative Technologies Laboratory, National Center for Scientific Research Demokritos (NCSR Demokritos)	Greece
Department of Physics, University of Milan (UniMi)	Italy
Department of Science and High Technology, University of Insubria	Italy
Interdisciplinary Centre for Nanostructured Materials and Interfaces (C.I.Ma.I.Na), Department of Physics “Aldo Pontremoli”, University of Milan (UniMi)	Italy
University of Cagliari	Italy
Italian Institute of Technology (IIT)	Italy
Department of Chemistry and Industrial Chemistry, University of Genoa	Italy

Department of Clinical Sciences and Community Health, University of Milan (UniMi)	Italy
University of Insubria	Italy
Department of Science and High Technology, University of Insubria	Italy
Chemical Engineering Contacts (Odours), University of Milan (UniMi)	Italy
Nano@Sens – Nanomaterials for Health and Environmental Sensors, Ca' Foscari University of Venice	Italy
Magna Graecia University of Catanzaro – Research Group in Computer Engineering, Bioinformatics and Medical Informatics	Italy
Polytechnic University of Marche (UNIVPM)	Italy
Department of Informatics, Bioengineering, Robotics and Systems Engineering, University of Genoa	Italy
SIMET Materials Testing Laboratory, Lecco Campus	Italy
CoMeTA – Corrosion Measurement Tools for Artefacts, Department of Applied Science and Technology (DISAT), Politecnico di Torino	Italy
Department of Chemistry, University of Milan (UniMi)	Italy
Department of Physics and Astronomy “Ettore Majorana”, University of Catania	Italy
Laboratory of Atmospheric Pollution, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	Italy
Institute of Atmospheric Pollution Research (IIA), National Research Council (CNR)	Italy
Institute of Science and Chemical Technologies “Giulio Natta” (SCITEC), National Research Council (CNR)	Italy
Institute for the Chemistry of OrganoMetallic Compounds (ICCOM), National Research Council (CNR)	Italy
Department of Information Engineering, Electronics and Telecommunications, Sapienza University of Rome	Italy
Academic & Research Innovation Technology Lab, IRCCS Venice	Italy
IRES Piemonte (Regional Institute for Economic and Social Research of Piedmont)	Italy
TERIN-SSI-EDS Laboratory, ENEA (Energy and Data Science Laboratory)	Italy
TERIN-SPV-DIN Laboratory, ENEA (Innovative Devices Laboratory)	Italy
Department of Electronics, Information and Bioengineering, Politecnico di Milano	Italy
Department of Science, Technology and Society, IUSS Pavia (University School for Advanced Studies)	Italy
Computer Science Laboratory, University of Pierre	Italy
ENEA CR-Portici, TERIN-FSD Department	Italy



Norwegian University of Life Sciences (NMBU)	Norway
Department of Informatics and Environmental Quality Research, Warsaw University of Technology (WUT)	Poland
University of Extremadura (UEX)	Spain
Barcelona Supercomputing Center (BSC)	Spain
Atmosphere, Aerosols and Climate Group, Spanish National Research Council (CSIC)	Spain
Institute of Environmental Diagnosis and Water Studies (IDAEA)	Spain
International Center for Numerical Methods in Engineering (CIMNE)	Spain
Environmental Research Center (CIMA)	Spain
Technical University of Madrid (UPM), Department of Chemical and Environmental Engineering, ETSII	Spain
Rocasolano Institute of Physical Chemistry	Spain
University Research Institute on Sustainability, Climate Change and Energy Transition (IU-RESCAT), Rovira i Virgili University (URV)	Spain
August Pi i Sunyer Biomedical Research Institute (IDIBAPS)	Spain
CARTIF Technology Center	Spain
MIND-IN2 UB, Department of Electronics and Biomedical Engineering, University of Barcelona (UB)	Spain
Institute for Bioengineering of Catalonia (IBEC)	Spain
Barcelona Institute for Global Health (ISGlobal)	Spain
Center for Energy, Environmental and Technological Research (CIEMAT)	Spain
Sensors and Biosensors Research Group, Autonomous University of Barcelona (UAB)	Spain
Electroanalysis Group, University of Barcelona (UB)	Spain
Microfabrication and Integration of Sensors and Energy Sources Group (MESSI), Institute of Microelectronics of Barcelona (IMB-CNM-CSIC)	Spain
Instrumentation, Sensors and Interfaces Group (ISI), Technical University of Catalonia (UPC)	Spain
Analytical Biosensors Group, University of Zaragoza (UNIZAR)	Spain
Chemical and Biosensors Group, Autonomous University of Madrid (UAM)	Spain
Radiation and Sensors Group, University of Alcalá (UAH)	Spain
Photochemistry and Sensors Group (FYS), Jaume I University (UJI)	Spain



Microelectronics and Microsensors Laboratory Group (MEMSlab), University of Valencia (UV)	Spain
Electroanalysis and (Bio)Electrochemical Sensors Group (GEBE), Complutense University of Madrid (UCM)	Spain
Electrochemistry and Bioanalysis Group (EQBA), IQS School of Engineering	Spain
Environmental Technologies Group, University of Cádiz (UCA)	Spain
ECSens, University of Granada (UGR)	Spain
Electrical and Bioengineering Group (INGELEC), University of La Laguna (ULL)	Spain
Electrical, Electronics and Communication Engineering, Public University of Navarre (UPNA)	Spain
Bioengineering and Environmental Engineering Research Group (BIOINGAMB), University of Castilla-La Mancha (UCLM)	Spain
Sensor Systems Research Group (GISS), University of Extremadura (UEX)	Spain
Industrial and Aerospace Engineering Department, University of Castilla-La Mancha (UCLM)	Spain
Smart Sensors Group, University of La Laguna (ULL)	Spain
Sensors and Instrumentation Techniques Group, Carlos III University of Madrid (UC3M)	Spain
Wireless Networks Group (WiNE), Open University of Catalonia (UOC)	Spain
Carlos III Health Institute (ISCIII), National Center for Environmental Health, Department of Atmospheric Pollution	Spain
Swiss Tropical and Public Health Institute (Swiss TPH)	Switzerland

Table 26. Industry & Technology Developers identified for Personal Exposure

Organization	Country
Biosency	France
Nanoz	France
RISA Security Analyses	Germany
DEUS Pollutrack Smart City	Germany
Infineon Technologies AG	Germany
ARIANET	Italy
Kunak Technologies – Air Quality Sensors	Spain
Envira IoT	Spain

Libelium	Spain
inBiot Monitoring (Mutilva)	Spain
NosmoTech Ltd.	United Kingdom

Table 27. Public Authority & Regulatory stakeholders identified for Personal Exposure

Organization	Country
French National Institute for Industrial Environment and Risks (INERIS)	France
Central Laboratory for Air Quality Monitoring (LCSQA)	France
German Environment Agency (UBA)	Germany
Regional Environmental Protection Agency of Piedmont (ARPA Piemonte)	Italy
Regional Environmental Protection Agency of Campania (ARPA Campania)	Italy
Regional Agency for Prevention, Environment and Energy of Emilia-Romagna (ARPAE)	Italy
Diputació de Barcelona	Spain
Ministry for the Ecological Transition and the Demographic Challenge (MITECO)	Spain
Spanish Society of Environmental Health (SESA)	Spain
Spanish Network of Cities for Climate (FEMP)	Spain
Madrid City Council	Spain

Table 28. Civil Society stakeholders identified for Personal Exposure

Organization	Country
Airparif	France

9.2 Annex 2. Stakeholder Mapping – Breath Analysis

The following tables present the organisations identified during the stakeholder mapping process specifically for the **Breath Analysis** use case. Personal contact details have been removed for data protection.

Table 29. Academic & Research stakeholders identified for Breath Analysis

Organization	Country
Department of Health Services Research and Policy, Research School of Population Health, College of Health and Medicine, Australian National University (ANU)	Australia
IMEC	Belgium
Laboratoire de Virologie et Immunologie Moléculaires (VIM)	France
Laboratory of Physics and Engineering of Grenoble (LIPhy), University Grenoble Alpes, CNRS	France
Infection and Chronic Inflammation Laboratory (2IC), University of Paris-Saclay / University of Versailles Saint-Quentin (UVSQ)	France
NanoMIR, Institute of Electronics and Systems (IES), University of Montpellier	France
Institute of Electronics, Microelectronics and Nanotechnology (IEMN), University of Lille	France
IMT Mines Alès	France
Department of Sensory Analytics and Technologies, Fraunhofer Institute for Process Engineering and Packaging (IVV)	Germany
Technical University of Dortmund (TU Dortmund)	Germany
Computational Systems Biology Group, Max Planck Institute for Informatics (MPI-INF)	Germany
University Medicine Rostock	Germany
Department of Diabetology, Heinrich Heine University Düsseldorf (HHU)	Germany
Fraunhofer Institute for Silicate Research (ISC)	Germany
Department of Chemistry and Pharmacy, Chair of Aroma and Smell Research, Friedrich-Alexander University Erlangen-Nürnberg (FAU)	Germany
Laboratory for Emerging Nanometrology (LENA), Institute of Semiconductor Technology (IHT), Technical University of Braunschweig (TU Braunschweig)	Germany
Fraunhofer Institute for Physical Measurement Techniques (IPM)	Germany
Institute of Chemical Engineering Sciences, Foundation for Research and Technology Hellas (FORTH/ICE-HT)	Greece
Institute of Molecular Biology and Biotechnology, Foundation for Research and Technology Hellas (IMBB-FORTH)	Greece
Medical School, University of Crete (UoC)	Greece



AirTechLab	Greece
Analytical Chemistry Department, National and Kapodistrian University of Athens (NKUA)	Greece
Inorganic Chemistry Department, National and Kapodistrian University of Athens (NKUA)	Greece
Biochemistry Department, National and Kapodistrian University of Athens (NKUA)	Greece
Physical Chemistry Department, National and Kapodistrian University of Athens (NKUA)	Greece
Biomedical Research Foundation of the Academy of Athens (BRFAA)	Greece
Smart Sensor Laboratory, Lambe Institute of Translational Research, College of Medicine, Nursing and Health Sciences, University of Galway	Ireland
CNR Research Area, Department of Chemistry and Industrial Chemistry, National Research Council (CNR)	Italy
University of Parma (UNIPR)	Italy
Politecnico di Milano (POLIMI)	Italy
Department of Electronic and Computer Bioengineering, University of Pisa (UNIPi)	Italy
Nanomaterials for Health and Environment Sensors (Nano@Sens), Ca' Foscari University of Venice (UNIVE)	Italy
Interdisciplinary Centre for Nanostructured Materials and Interfaces (C.I.Ma.I.Na), Department of Physics "Aldo Pontremoli", University of Milan (UNIMI)	Italy
Italian Institute of Technology (IIT), Smart Materials	Italy
Section of Chemical Engineering (Odours), University of Milan (UNIMI)	Italy
Biometry, Biosignals, Safety and Smart Mobility Group, Technical University of Madrid (UPM)	Spain
Biochemistry and Molecular Biology "B" and Immunology, University of Murcia (UMU)	Spain
Biodiversity and Environment Institute (BIOMA), University of Navarra (UNAV)	Spain
Engineering for Circular Economy (E4EC), University of Alicante (UA)	Spain
Department of Chemical Engineering (EQ), Technical University of Catalonia (UPC)	Spain
Innovation in Materials and Molecular Engineering (IMEM), Technical University of Catalonia (UPC)	Spain
Computational Biology and Complex Systems (BIOCOMSC), Technical University of Catalonia (UPC)	Spain
Signal and Information Processing for Sensing Systems, Institute for Bioengineering of Catalonia (IBEC)	Spain



Department of Chemical and Analytical Engineering, University of Barcelona (UB)	Spain
Chemometrics and Sensory Analysis for Analytical Solutions (CHEMOSENS), Rovira i Virgili University (URV)	Spain
Analytical and Environmental Chemistry Research Group, University of Girona (UdG)	Spain
Analytical Chemistry, Environment and Chemometrics (QAMAQ), University of Valladolid (UVa)	Spain
Industrial Equipment Design Center, Technical University of Catalonia (UPC)	Spain
Biomarkers in Fluids and Translational Neurology Research Group, BarcelonaBeta	Spain
Chemistry Department, University of Girona (UdG)	Spain
Arrhythmias and Physical Activity Research Group, August Pi i Sunyer Biomedical Research Institute (IDIBAPS)	Spain
Inflammation and Repair in Respiratory Diseases Research Group, August Pi i Sunyer Biomedical Research Institute (IDIBAPS)	Spain
Respiratory Biophysics and Bioengineering Research Group, University of Barcelona (UB)	Spain
Photonic Technologies Group (GTF), Institute for Research in Engineering of Aragon (I3A)	Spain
Analytical Research and Innovation (IBeA), University of the Basque Country (UPV/EHU)	Spain
Bellvitge Biomedical Research Institute (IDIBELL), Scientific Director CIBERES	Spain
Cooperative Research Center in Biomaterials (CIC biomaGUNE)	Spain
Biomedical Research Network on Respiratory Diseases (CIBERES)	Spain
Foundation for Health Research Management of Seville	Spain
Tissue Microenvironment Laboratory (TME Lab), Institute for Research in Engineering of Aragon (I3A)	Spain
Gas Chromatography–Mass Spectrometry, Ramón y Cajal Institute for Health Research (IRYCIS)	Spain
Pneumology Department, Bellvitge Biomedical Research Institute (IDIBELL)	Spain
GREC, Research Institute of Hospital de la Santa Creu i Sant Pau (IR Sant Pau)	Spain
Microfabrication and Integration of Sensors and Energy Sources Group (MESSI), Institute of Microelectronics of Barcelona (IMB-CNM-CSIC)	Spain
Institute for Bioengineering of Catalonia (IBEC)	Spain
Environmental Technologies Group, University of Cádiz (UCA)	Spain

Particle Technology Laboratory, Department of Mechanical and Process Engineering (D-MAVT), ETH Zürich	Switzerland
Biomedical Sciences and Biomedical Engineering, University of Reading	United Kingdom
Department of Computer & Information Sciences, Towson University	USA

Table 30. Industry & Technology Developers identified for Breath Analysis

Organization	Country
Nanoz	France
Biosency	France
Alpha MOS	France
Air Liquide Santé	France
Infineon Technologies AG	Germany
Drägerwerk AG & Co. KGaA	Germany
Bosch Sensortec	Germany
inBiot Monitoring (Mutilva)	Spain
Libelium	Spain
Sensirion AG	Switzerland
Axetris AG	Switzerland
Owlstone Medical	United Kingdom

Table 31. Public Authority & Regulatory stakeholders identified for Breath Analysis

Organization	Country
National Agency for Food, Environmental and Occupational Health Safety (ANSES)	France
National Metrology Institute of Germany (PTB)	Germany
National Organization for Medicines (EOF)	Greece

Table 32. Civil Society stakeholders identified for Breath Analysis

Organization	Country
Hellenic Thoracic Society (HTS)	Greece
Spanish Society of Pulmonology (SEPAR) Innovation Committee	Spain

9.3 Annex 3. Preliminary questionnaire on personal exposure use case

Introduction: AMUSENS (EU grant agreement no. 101130159) is a European project that aims at developing a gas sensor platform with flexible selectivity to adapt to different gas environments. This approach combines multi-pixel gas-sensitive surfaces with artificial intelligence to enhance data analysis for specific applications.

This questionnaire aims to better understand the profiles and needs related to one of key use cases studied in AMUSENS project: individual exposure to air pollutants.

Data Protection & Consent

1. **Email address:** [_____]

2. **GDPR Consent:** Under the European Regulation 2016/679 (GDPR), we inform you that your data will be included in a file owned by Science for Change S.L. for the AMUSENS Project. You may exercise your rights by emailing hello@scienceforchange.eu.

- Accept
- Decline

00. General information

3. **Education level:**

- University
- Non-university

4. **Occupation:** [_____]

5. **Do you spend most of your time...**

- Indoors
- Outdoors

01. General understanding and motivation

6. **For which reason(s) would you be interested in assessing exposure to gases? (Multiple choice)**

- Health issues
- Organizational requirements
- Public demand
- Research purposes
- Curiosity
- A desire to implement changes
- Other: _____

7. **What level of knowledge and/or experience do you have with indoor air quality monitoring?**

- None



- Basic
- Familiar
- Specialist in the field

02. Sensor application & Exposure context

8. In which settings do you see the highest need for monitoring exposure? (Multiple choice)

- Workplace
- Public spaces
- Transport
- Home
- School
- Other: _____

9. Considering your daily activities, would you prefer a:

- Wearable device (e.g. wristband, smartwatch, clip-on, pendant)
- Fixed device (e.g. wall-mounted, attached to machinery, integrated into desk)
- Device located on a mobile instrument (e.g. trolley)
- Other: _____

10. Which features are most relevant regarding your previous selection? (Multiple choice)

- Wearable case
- Real-time data display
- Transmission for data retrieval
- Other: _____

11. Are there ergonomic considerations or environmental conditions specific to your tasks that should be considered? [_____]

03. Utility and interpretation of data

12. As a potential end-user, what is the longest period you would be willing to use this monitoring system?

- One day
- One week
- One month
- Continuously

13. Based on your work profile and activities, which times of day do you find air quality measurements most valuable, and why? [_____]

14. Which parameters do you consider essential to monitor in indoor spaces? (Multiple choice)

- Gas concentration
- Cumulative dose
- Type of gas
- Other: _____



15. Is individualized air quality monitoring necessary in every room of a home or workplace? If not, which areas would you prioritize? [_____]

16. Would you be willing to recharge the sensor periodically if it improves continuous monitoring accuracy?

- Yes
- No

04. Awareness and behavioural change potential

17. Do you think workers, staff, and managers would be interested in having access to a risk analysis tailored to their work environments (schools, offices, etc.)? Why? [_____]

18. What qualitative data could help enhance end-users' understanding of the AMUSENS sensor outputs? (Multiple choice)

- A colour scale associated with the air quality index.
- Descriptive labels or categories (e.g., "Good," "Moderate," "Poor") based on the sensor data.
- Visual indicators, such as icons or graphics, representing common pollutants detected.
- Other: _____

19. Are you willing to provide additional information beyond exposure data? [_____]

20. Would you be willing to fill in a precise survey on this information?

- Yes
- No, it would take too much time
- No, it would require too much energy

21. Do you prefer...

- Single parameter indicator of the concentrations of different gases.
- Multi-parametric indicator (an indicator that combines a range of scientific information into a single, easy-to-read scale)

22. Should the data be...

- In Real-time
- Averaged over time

23. In what form do you want the information?

- Directly on the sensor
- In a mobile app or platform
- Provided and interpreted by an expert

24. Do you think an indoor air quality monitoring system should also display outdoor air quality to help decide when to ventilate the space?



- Yes
- No

25. Are you concerned about the reliability of the data measured by the sensor?

- Yes
- No

26. What factors would increase your confidence in the quality and accuracy of the generated data? [_____]

9.4 Annex 4. Dimensions and items of the Personal Exposure Use Case survey

Section	Item	Response Type / Scale
0. General information	Education level	Single-choice categorical
	Time predominantly spent	Single-choice categorical
1. General understanding and motivation	Reasons for interest in assessing exposure to gases	Multiple-selection categorical with write-in
	Level of knowledge/experience with IAQ monitoring	Single-choice ordinal (None to Specialist)
2. Sensor application	Preferred type of monitoring device	Single-choice categorical with write-in
	Most relevant device features	Multiple-selection categorical with write-in
	Longest period willing to use the monitoring system	Single-choice categorical
3. Utility and interpretation of data	Essential parameters to monitor in indoor spaces	Multiple-selection categorical with write-in
	Willingness to recharge the sensor periodically for improved accuracy	Single-choice binary (Yes/No)
4. Awareness and behavioural change potential	Qualitative data to enhance end-users' understanding of sensor outputs	Multiple-selection categorical with write-in
	Willingness to fill in a precise survey on additional information	Single-choice categorical (Yes; No, due to time; No, due to energy)
	Preference for single parameter vs. multi-parametric indicator	Single-choice categorical
	Preference for data timing (real-time vs. averaged)	Single-choice categorical
	Preferred form of information delivery	Single-choice categorical
	Concern about the reliability of the data measured by the sensor	Single-choice binary (Yes/No)

9.5 Annex 5. Preliminary questionnaire on breath analysis

Introduction: AMUSENS (EU-funded - Grant Agreement No. 101130159) is a European project aiming to revolutionize how we detect and interpret gases, both in the environment and in the human body. How? Through multi-pixel gas sensors combined with artificial intelligence, adaptable to a wide range of scenarios and applications.

One of the main challenges we're focusing on is breath monitoring—a way to detect early signs of health changes without the need for invasive tests. Breath analysis means measuring the gases you breathe out to learn more about how your body is working - like your metabolism, stress levels, or early signs of illness.

This questionnaire will help us better understand who you are, what you need, and how this technology could become truly useful in real life.

Data Protection & Consent

1. **Email address:** [_____]

2. **GDPR Consent:** Under the European Regulation 2016/679 (GDPR), we inform you that your data will be included in a file owned by Science for Change S.L. for the AMUSENS Project. You may exercise your rights by emailing hello@scienceforchange.eu.

- Accept
- Decline

00. General information

3. **Education level:**

- University
- Non-university

4. **What is your current role or area of expertise?**

- Researcher
- Healthcare professional (e.g. doctor, nurse, dietitian)
- Fitness/wellness professional (e.g. trainer, coach)
- Public health or policy expert
- Technology developer / engineer
- General public / potential user
- Other: _____

5. **Do you have knowledge and/or experience with breath analysis monitoring?**

- None
- Basic
- Familiar
- Specialist in the field / Expert

6. **Have you used a breath analysis monitoring device?**



- Yes
- No

7. If yes, which ones? (e.g. alcohol breathalyzer, asthma monitor, ketone meter):

8. For which application(s) did you use them? (e.g. health tracking, sports performance, medical treatment, recreational use):

9. What were the main shortcomings you observed? (e.g. too cumbersome, too expensive, unreliable results, hard to understand output):

10. In which contexts do you think breath analysis would be most useful? (Select all that apply)

- Personal health tracking
- Fitness/workout
- Diet performance
- Disease detection or prevention
- Stress monitoring
- Other: _____

01. Potential Use Cases

Scale: 1 (Not useful) - 5 (Essential)

11. Monitoring fat loss or ketosis during a diet: (1) (2) (3) (4) (5)

12. Tracking stress, fatigue or workout intensity: (1) (2) (3) (4) (5)

13. Detecting respiratory infections or viral illness: (1) (2) (3) (4) (5)

14. Are there other breath-related use cases you find promising?

02. Usage Scenarios

15. In the context of the following use cases, what is the periodicity you would find useful for you (or others) to use a breath analyser? Options: Multiple times per day / Once per day / A few times per week / Occasionally (e.g. illness, intense workouts) / Not sure

- **Monitoring fat loss or ketosis during a diet:** [Select one]
- **Tracking stress, fatigue or workout intensity:** [Select one]
- **Detecting respiratory infections or viral illness:** [Select one]

16. How would you prefer to use a breath analysis device? Options: Self-monitoring / With help from a professional

- **Monitoring fat loss or ketosis during a diet:** [Select one]
- **Tracking stress, fatigue or workout intensity:** [Select one]
- **Detecting respiratory infections or viral illness:** [Select one]



17. In which contexts would this type of device be most useful? Options: At home / In the workplace / In clinical or diagnostic settings / In fitness or sports centres / On the go/during travel / Other

- **Monitoring fat loss or ketosis during a diet:** [Select multiple]
- **Tracking stress, fatigue or workout intensity:** [Select multiple]
- **Detecting respiratory infections or viral illness:** [Select multiple]

18. Other: Please specify [_____]

03. Sensor Features & Preferences

19. What type of device format do you think would be most suitable for breath analysis?

- () Device at a fixed location
- () Handheld breathalyzer (portable) connected to a mobile phone App
- () Other: _____

20. Which features are most important to you in the case of Monitoring fat loss or ketosis during a diet? Rate importance: Not important / Slightly / Moderately / Very / Essential / Don't know

- Ease of use
- Comfort / wearability
- Real-time feedback
- Data accuracy / reliability
- Smartphone connectivity
- Battery life / autonomy
- Low cost / affordability
- Indicator on the device

21. Which features are most important to you in the case of Monitoring fat loss or ketosis during a diet?

- Others: [_____]

22. Which features are most important to you in the case of Detecting respiratory infections or viral illness? Rate importance: Not important / Slightly / Moderately / Very / Essential / Don't know

- Ease of use
- Comfort / wearability
- Real-time feedback
- Data accuracy / reliability
- Smartphone connectivity
- Battery life / autonomy
- Low cost / affordability
- Indicator on the device

23. Which features are most important to you in the case of Detecting respiratory infections or viral illness?

- Others: [_____]



24. Which features are most important to you in the case of Tracking stress, fatigue or workout intensity? *Rate importance: Not important / Slightly / Moderately / Very / Essential / Don't know*

- Ease of use
- Comfort / wearability
- Real-time feedback
- Data accuracy / reliability
- Smartphone connectivity
- Battery life / autonomy
- Low cost / affordability
- Indicator on the device

25. Which features are most important to you in the case of Tracking stress, fatigue or workout intensity?

- Others: [_____]

26. To ensure the sensor works accurately, it may need to be calibrated from time to time. Which of the following calibration options would you find acceptable?

- I'm willing to do a simple calibration process myself at home (e.g., using an app or small device).
- I'd prefer to bring the sensor to a local shop or facility for calibration.
- I'd be willing to pay for a charging station that also calibrates the sensor.
- I would not be willing to do any calibration.

27. What qualitative data could help enhance end-users' understanding of the sensor outputs? (Multiple choice)

- A colour scale.
- Descriptive labels or categories.
- Visual indicators, such as icons or graphics, representing health status.
- Other: _____

04. Data and Trust

28. What are your main concerns (if any) about breath sensors? (Multiple choice) *Options per use case: Results accuracy / Misuse of data / Device discomfort / Maintenance & calibration / Cost / Privacy & data sharing / Monitoring health needs / Reliability / Hygiene*

- **Monitoring fat loss or ketosis during a diet:** [Select multiple]
- **Tracking stress, fatigue or workout intensity:** [Select multiple]
- **Detecting respiratory infections or viral illness:** [Select multiple]

29. Other concerns: Please specify [_____]

30. Would you be interested in using a cloud-connected breath analysis device that stores your data, provides personalized recommendations, and allows sharing results with professionals? *Options: Yes I'd find it useful / Yes but I have concerns about privacy / No I prefer fully offline devices / I'm not sure*

- **Monitoring fat loss or ketosis during a diet:** [Select one]
- **Tracking stress, fatigue or workout intensity:** [Select one]



- **Detecting respiratory infections or viral illness:** [Select one]
-

05: Final Thoughts

31. What would motivate you (or others) to use this kind of technology?
[_____]

32. Depending on the use case, would you be willing to provide more general information about your habits?

- Yes
- No

33. Do you have any other comments, suggestions or concerns? [_____]